IRRIGATION TRIALS IN THE SOUTHWEST REGION

By

C.H. DIEBOLD, Soil Scientist

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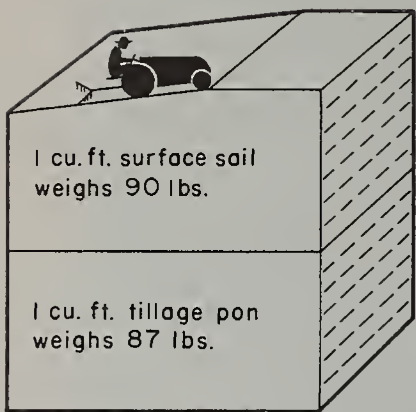
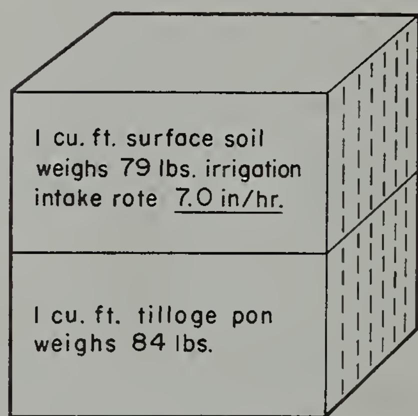
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
REGION 6 ALBUQUERQUE, ~~NEW MEXICO~~
M-352

TILLAGE COMPACTS THE SOIL

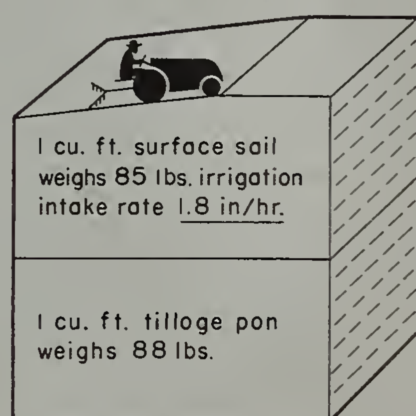
ESPECIALLY WHEN MOIST
(DURABLE BALL)



OCTOBER 1948
CULTIVATED 16 TIMES



MARCH 1949
CHISELED AND PLOWED



JUNE 1949
CULTIVATED 6 TIMES
AND IRRIGATED ONCE

ROSWELL SOIL CONSERVATION DISTRICT

DEEP MEDIUM TEXTURED SOIL

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Introduction

In 1945, the author began to make irrigation trials at the Albuquerque Nursery in connection with grass seed production problems. Problems of fertilization and production were related to differences in soil units. We needed to know how much water was required to bring the root zone of different soils to field capacity and how fast water entered the different soils. How did these data relate to leveling practices and irrigation layout?

These studies were later extended to other parts of New Mexico as well as Colorado, Utah and Arizona in order to relate the data to similar soil units in these states. This report covers the field work for seven years, conducted by the Regional Office of the Soil Conservation Surveys Division of the Branch of Operations, in cooperation with the Albuquerque Nursery, Tucson Nursery, Regional and State Offices and a number of work groups in Region 6. Laboratory analyses were made by the cooperative Soil Conservation Service Laboratories and the Regional Soils Laboratory. The author gratefully acknowledges the cooperation of more than one hundred Soil Conservation Service technicians in the 87 border irrigation and 37 furrow irrigation trials. Detailed soil moisture studies were made, before and after irrigation in 78 trials. Detailed volume weight studies were made at 50 sites. At most of these sites core intake rates of several soil layers were determined.

The Division of Irrigation of the Soil Conservation Service, the State Experiment Stations and other agencies have conducted irrigation trials for many years. Many valuable contributions have resulted. Nevertheless, we still need to know how to project the data in relation to the operations program of the Soil Conservation Service. This report _may serve as a guide_ until more detailed information is available.

III

Summary

Eight textural separations and 13 types of geologic or underlying material have been grouped into five different readily available moisture values. Some of these values for the surface foot are 2.1 inches per foot for medium to fine textured soils, 1.2 in/ft for moderately coarse textures and .7 in/ft for clean sands and gravel with coarse textured material.

Field capacity values within textural separations were independent of volume weight when expressed on a volume basis. Field capacity values, inches per foot, are given for each textural separation.

The ball test appears to be the most practical method of estimating readily available moisture in medium to fine textured soils. Clues are given.

Moisture use values during rapid growth of alfalfa, expressed in inches per foot for the 0-5 foot depth (MUD) can be used to subgroup soil units, to determine maximum land use capability, and as an aid in designing irrigation layouts for the maximum depth of water required.

Moisture use values during rapid growth of row crops, small grains and grasses (MUS) are presented for the 0-3 foot depth for different textures and materials. Such values are helpful in designing irrigation layouts for the minimum depth required per average irrigation for these crops.

Three degrees of compaction (volume weights) have been proposed, based on permeability data and irrigation intake rates. The limits of compaction are similar for medium silty to fine textures but are different for the remaining textural classes.

Compaction decreases the volume of temporary storage and increases the depth of soil required to store temporarily average irrigations. At 1/4 readily available moisture, layers limiting intake rates during three inch irrigations in firm soils occur within the surface foot and within the 0-2 foot depth for five inch irrigations. In contrast, layers limiting intake rates may occur at appreciably greater depths in compact soils than in firm soils, especially in the moderately fine and fine textured soils.

The degree of compaction of the limiting layer in the surface foot is one of the most important factors influencing average irrigation intake rates within a textural class. Tillage by farm machinery may either increase or decrease intake rates, depending upon the moisture conditions present. In terms of inches per hour, tillage changes intake rates more in stable soils than in unstable soils. However, tillage can change appreciably the length of time required to irrigate unstable soils.

Wide variations in average irrigation intake rates preclude the use of texture alone in estimating intake rates. The widest spread occurred in medium textured soils containing less than 40% silt, and the narrowest spread in medium textured soils containing more than 40% silt and less than 3% organic matter, Ʒ. The Ʒ soils usually have intake rates of less than one inch per hour and, frequently, less than .5 in/hr if they slake with less than 10 drops of water. In general, differences in compaction, number of effective pores and, to a lesser extent, stability, cause wide differences in intake rates within the other textural separations.

Alkali-affected soils are unstable and have low irrigation intake rates.

The range in readily available moisture, 0-3/4, present prior to irrigation was a minor factor affecting both border and furrow irrigation intake rates.

Field methods are given for estimating volume weight, stability and for separating medium textured soils containing more than 40% silt from those containing less than 40% silt.

Although procedures are given for satisfactorily predicting irrigation intake rates using core intake rates from Uhland cores and storage values, core intake rates have been of more value in locating layers which limit irrigation intake rates.

Three irrigation intake rate classes are proposed: slow 0.0 - 1.0 in/hr., moderate 1.0 - 2.5 in/hr., and excessive more than 2.5 in/hr. Clues are given for grouping soils by intake rate classes; suggestions are given for irrigation trials suitable for determining the correct intake rate class.

Eliminating surface waste water resulted in an average irrigation efficiency of 81% for 21 border irrigations at the

Albuquerque Nursery. Deep percolation losses are not only serious on soils with MUD values of 3.0 - 3.9 inches moisture but may be serious on soils with MUD values of 5.0 - 6.0 inches. The minimum depth of water that will adequately cover an area is primarily determined by the intake rate. Recognition of both the correct intake rate class and the volume of moisture required to fill the root zone are essential in reducing deep percolation losses.

The highest degree of leveling is required on soils with intake rates of less than 1.0 in/hr., in order to obtain uniform penetration of moisture and efficient use of water. Less refined methods are required for soils with higher intake rates but, even here, uniform cross slopes and the elimination of high spots are important for adequate water penetration. Whether the grade is .1 or .3% appears to be of less significance than elimination of high spots.

Suggested lengths of borders for high irrigation efficiencies and uniformity of penetration by intake rate classes and classes of moisture use (MUD) are presented.

At least two groups of soils should be recognized in setting up maximum allowable streams for furrow irrigation by per cent of slope.

READILY AVAILABLE MOISTURE

Definition: Our soil moisture studies in both semi-arid and arid areas show that most crops exhibit symptoms of stress or wilting when appreciable quantities of available moisture still remain in the subsoil and substratum. Although this moisture is important for survival, growth is retarded and ceases well above wilting point. Thus, readily available moisture is the volume of moisture expressed as inches depth of water per foot depth of soil between field capacity and the level at which plants with mature root systems begin to show stress.

Laboratory Methods: The lower limit of readily available moisture is appreciably above wilting point. Blair, Richards and Campbell (1) found that the growth of sunflowers was markedly reduced at moisture contents considerably above the permanent wilting percentage. Furr and Reeve (8) found that an average of 20% of the available moisture is held within the wilting range. Wilting point values are not satisfactory for estimating the lower limit of readily available moisture. Instead, wilting point values indicate the lower limit of moisture available to plants for survival.

The upper limit of readily available moisture is often estimated in the laboratory by determining the moisture equivalent. Moisture equivalent values are similar to field capacity values for most medium and moderately fine textures. Moisture equivalent values are appreciably below field capacity for moderately coarse and coarse textures and are often too high for fine textures. Peele and Beale have recognized this and developed an equation (14.) Richards and Weaver (15) have shown that the amount of moisture retained at field capacity is similar to the amount of moisture retained at one-third atmosphere. However, for coarse textured soils [1] the Bureau of Reclamation (12) at Yuma, Arizona, has found that 1/10 atmosphere is comparable to field capacity. Although such laboratory data are helpful, we also need actual field determinations of soil moisture in many areas before we can use laboratory data with assurance.

1 The term coarse will be used instead of light texture and, likewise, fine instead of heavy texture, in order to avoid confusion when discussing compaction.

Field Method: To determine the lower limit of readily available moisture, we obtained the volume of moisture present by one foot depths at 18 locations just before irrigating fields occupied by crops with mature root systems. Previously, the crop had been showing stress, usually from one to three days, in the afternoon. Either the root zone had been brought to field capacity during the preceding irrigation or we excluded those depths where inadequate penetration occurred.

The upper limit of readily available moisture, field capacity, was determined by taking soil moisture samples two days after irrigation near the same 18 locations sampled prior to irrigation. Although field capacity has been defined by some as the volume of water retained by the soil after gravitational water or free water has drained away, this is not literally practical. In well drained soils, nearly all of the free water has drained downward out of the root zone within a period of two days. If one delays longer, consumptive use of capillary moisture will more than offset the loss of free water. Therefore, the field capacity values reported were taken two days after irrigation. In Table 1, values of average readily available moisture for the surface foot are given.

Texture affects readily available moisture: Although texture is the primary factor affecting the volume of readily available moisture, medium to fine textures have similar readily available moisture capacities. Based on 26 irrigation trials, the average readily available moisture capacity of medium, moderately fine and fine textures was 2.02 $\pm$ .06 inches per foot. The standard error of $\pm$ .06 means that two-thirds of the individual values occurred between 1.96 and 2.08 inches per foot. The average values by texture are as follows: fine 2.2, moderately fine 2.0, medium (40% silt plus) 2.1 and medium (0-39% silt) 1.9 inches per foot. These values were derived from the surface foot. Owing to variations within texture, separate mean values do not appear to be justified at this time. Likewise, we have retained the value of 2.1 inches per foot in Table 1 for medium to fine textures, which was reported in Regional Bulletin 106, (4).

Table 1: Readily available moisture and field capacity expressed as inches, depth of water per foot, depth of soil by textures and kind of materials:

Texture or Material	Average Readily Available Moisture[c]	Field Average	Capacity Limits
1 Fine	2.1	5.0	4.7 - 5.5
2 Moderately fine	2.1	4.0	3.8 - 4.6
$\overline{3}$ Medium (40%+ silt)	2.1	3.7	3.4 - 4.2
3 Medium (0-39% silt)	2.1	3.2	2.7 - 4.0
4 Moderately coarse, 03 Gravelly medium	1.2	2.2	1.7 - 2.7
5 Coarse	1.0	1.6	1.5 - 1.8
$\overline{0}$3 Very gravelly	.7	1.3	.5 - 1.5
Kind of Material:			
H Gravel and/or cobble with medium texture	1.2	2.2	1.7 - 2.7
K Gravel and/or cobble embedded in high lime zone[b]	1.2	2.2	1.7 - 2.7
G Gypsum[a], L Marl[a] or soft caliche	1.2	-	- - -
P Sand, J Gravel and/or cobble with coarse texture	.7	1.3	.5 - 1.5
A Acid Igneous, B Basic Igneous	.0	.0	.0 ?
E Shales consolidated, F Limestone and Caliche	.0	.0	.0 ?
M Sandstone consolidated, N Sandstone poorly consolidated	.0	.0	.0 ?

a L and G have field capacities similar to the textural class they most nearly approach. C, poorly consolidated shales, have readily available moisture values similar to H for the first foot and, below that, they are similar to E.

b Apparently most of the K mapped is similar to H; however, the one detailed study made at Provo indicated that it was not as good as J.

c Surface foot.

Our field data show that there is a very sharp drop in readily available moisture between 3 (medium) and 4 (moderately coarse) textures. The break occurs at 30 to 35% silt plus clay. Moderately coarse textures as well as gravelly fine sandy loams (10-45% gravel by volume) hold an average of 1.2 inches per foot of readily available moisture. The upper limit of readily available moisture within this group is 1.5 in/ft and the lower limit is 1.0 in/ft. 5 (coarse) textures occupy a very narrow range from .9 to 1.0 in/ft. P (clean sands.) J (gravelly, with coarse textured material, and medium textured material containing more than 45% gravel by volume) hold approximately 0.7 in/ft of readily available moisture. Certain geologic materials such as A (acid igneous bed rock,) B (basic igneous bed rock,) etc., shown in Table 1 are given a value of .0 since these materials inhibit root development. In conclusion, eight textural separations and 13 types of material have been grouped into five different readily available moisture values.

Volume weight appears to be a minor factor affecting readily available moisture; at least insofar as it affects field capacity when expressed as inches per foot. For example, the average field capacity of 12 medium textured soils (0 - 39% silt) was 3.2 in/ft when the average volume weight was 1.35. For 10 soils of the same texture but with an average volume weight of 1.62, the field capacity was almost identical, 3.1 in/ft. Similar field capacity values were observed in other texture classes for soils differing widely in volume weight. Field capacity values within textural classes were independent of volume weight when expressed on a volume basis.

Does organic matter increase the amount of readily available moisture? In terms of readily available moisture expressed in inches per foot, organic matter is similar to clay. Likewise, it has a high percentage of unavailable water. Organic matter tends to fluff the soil. Accordingly, on a percentage basis, organic matter increases the percentage of moisture held at field capacity but the volume weight is usually less. As a result, additions of organic matter usually do not increase the volume of readily available moisture in medium to fine textures (6) but the volume of readily available moisture can be increased in both moderately coarse and coarse textured soils by the addition of organic matter.

Quick Estimates of Field Capacity: You can make a usable estimate of field capacity by using the values given in Table 1. Remember that field capacity values are expressed on an oven dry basis and consequently include moisture that is not readily available. The average values given in Table 1 should be

adjusted if the texture is approaching another textural class. Individual values of field capacity for non-gravelly soils are shown in Figure 1. Note that the field capacities of medium textured soils containing more than 50% silt are similar to moderately fine textures. You can interpret the effect of the percentage of gravel, both by weight and by volume, upon field capacity in Figure 2. Medium textured gravelly subsoils containing more than 45% gravel by volume have field capacities of less than 1.5 inches per foot and are therefore included with J, gravelly subsoils with light textured material. Until detailed soil moisture studies are made, field capacity values from Table 1 should suffice.

Field Estimates of Readily Available Moisture

How much moisture is in the ground when you need to irrigate? For most row crops, you do not need to irrigate for several days when more than half of the available moisture is present in the 6 - 12 inch depth. In contrast, growth has slowed up and you usually need to irrigate at once when less than 1/4 of the available moisture is present. So you normally plan to irrigate some time when 1/4 - 1/2 of the readily available moisture is present in the 6 to 12 inch depth. Now, if you can estimate the percent of readily available moisture, you can also estimate how many inches of water are needed to bring the root zone to field capacity.

The <u>Ball test</u> appears to be the most practical of the several methods tried for estimating readily available moisture in medium to fine textured soils. Squeeze the ball of soil three or four times just like milking a hard milking cow -- <u>not too much, not too little</u>. If the soil is too dry to form a ball, you have less than 1/4 readily available moisture but, if it will form a ball, you have at least 1/4 readily available moisture. If the ball stays intact after tossing it five times, one foot into the air and catching it as you would a baseball, it is durable and you have more than 1/2 available moisture. If it breaks with less than five throws, you have 1/4 - 1/2 readily available moisture present. (Soils with less than 15% clay are more difficult to ball than those with higher clay contents.) When medium to fine textured soils approach field capacity, they become sticky. You probably have 3/4 to field capacity when a thickness of 1/50 inch or more sticks to your thumb upon squeezing the ball. At field capacity, a thin film of moisture will be visible for one or two seconds on your finger after squeezing a ball of soil. (Note, films are difficult to detect if you

have handled machine oil.) Heavy films of moisture indicate that the soil is appreciably above field capacity. These clues have been summarized in Table 2.

Our data from Arizona, New Mexico, Utah and Colorado indicate that the ball test deserves widespread trial in estimating readily available moisture.

Table 2: Correlation of readily available moisture with field clues for medium to fine textured soils (tentative.)

Available Moisture	Inches of Water Needed per Foot	Clues for Medium to Fine Soils: Balls	Film of Moisture on Clean Finger
0 - 1/4	2.1 - 1.5	Will not form	None
1/4 - 1/2	1.5 - 1.0	Fragile	None
1/2 - 3/4	1.0 - .5	Durable, not sticky	None
3/4 - F	.5 - .0	Durable, usually sticky	At F light film may evaporate in 1 or 2 seconds[a].
F +	.0		Free water easily visible. Film may stay on finger several seconds.

a. In a semi-arid climate.

As yet, we have not found a satisfactory method for estimating readily available moisture in moderately coarse and coarse textured soils. In both textural classes you can usually form a ball at 1/4 readily available moisture. The balls often remain fragile even at field capacity, especially in the coarse textures. Here the amount of clay is quite important. Just as in the finer textures, the soils become harder when less than 1/4 readily available moisture is present.

A tiling spade is sometimes useful in estimating the amount of readily available moisture if you know the degree of compaction. For example, at the Albuquerque Nursery, in soils which are firm, the tiling spade can be easily shoved in by hand when more than one-half readily available moisture is present in medium to fine textures. When 1/4 to 1/2 readily available moisture is present, you can shove the spade down with your foot but it requires considerable strength. At moisture contents below 1/4 readily available moisture, the average person has to jab the spade in order to penetrate the soil. In compact soils, however, even at field capacity, you have to jab the spade in order to penetrate

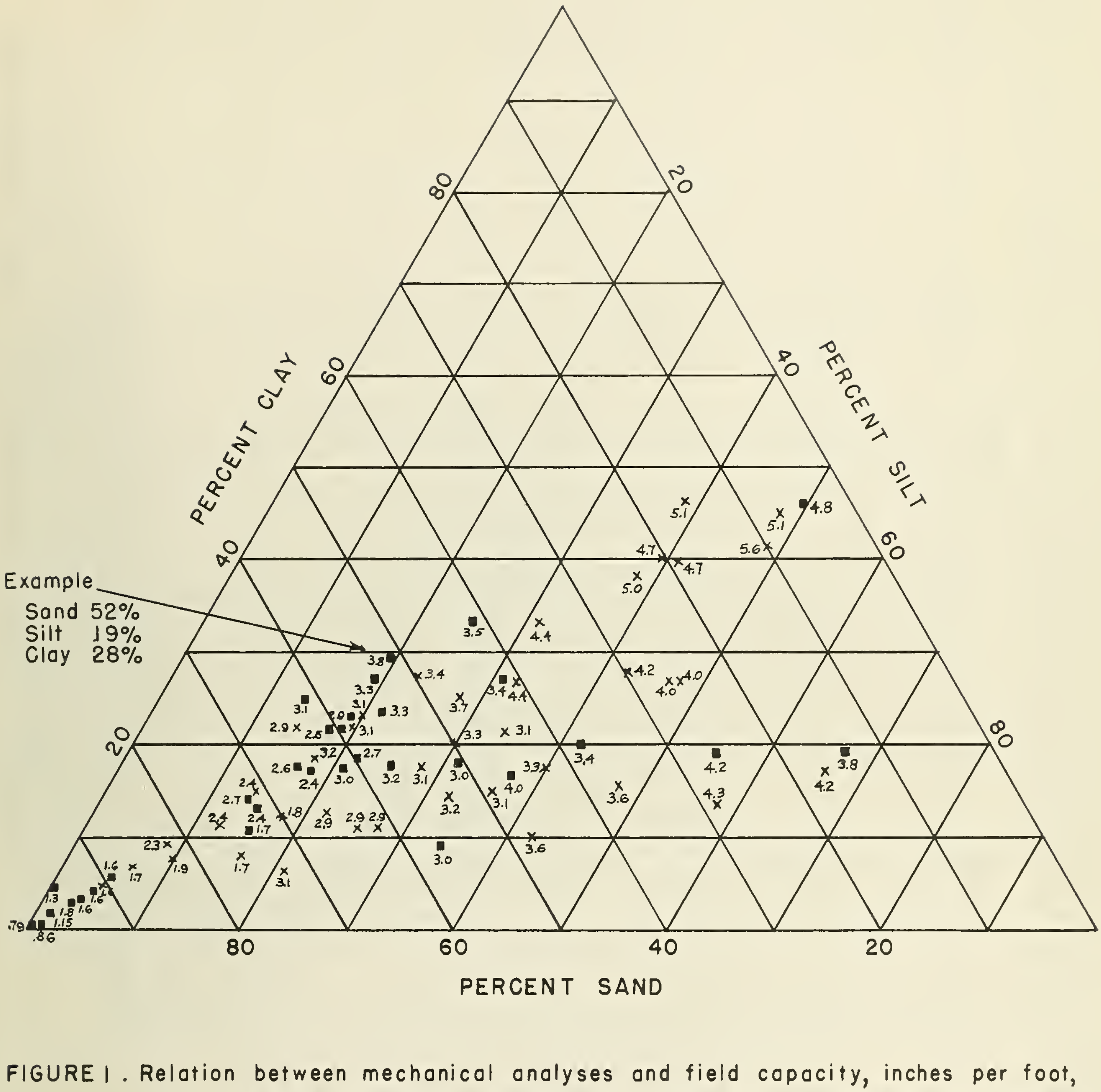

FIGURE 1. Relation between mechanical analyses and field capacity, inches per foot, two days after irrigation (×) surface foot, and (■) second and third foot on irrigated lands in Arizona, Colorado, and New Mexico.

THE FIELD CAPACITY OF GRAVELLY SOILS DECREASES AS THE PERCENTAGE OF GRAVEL INCREASES

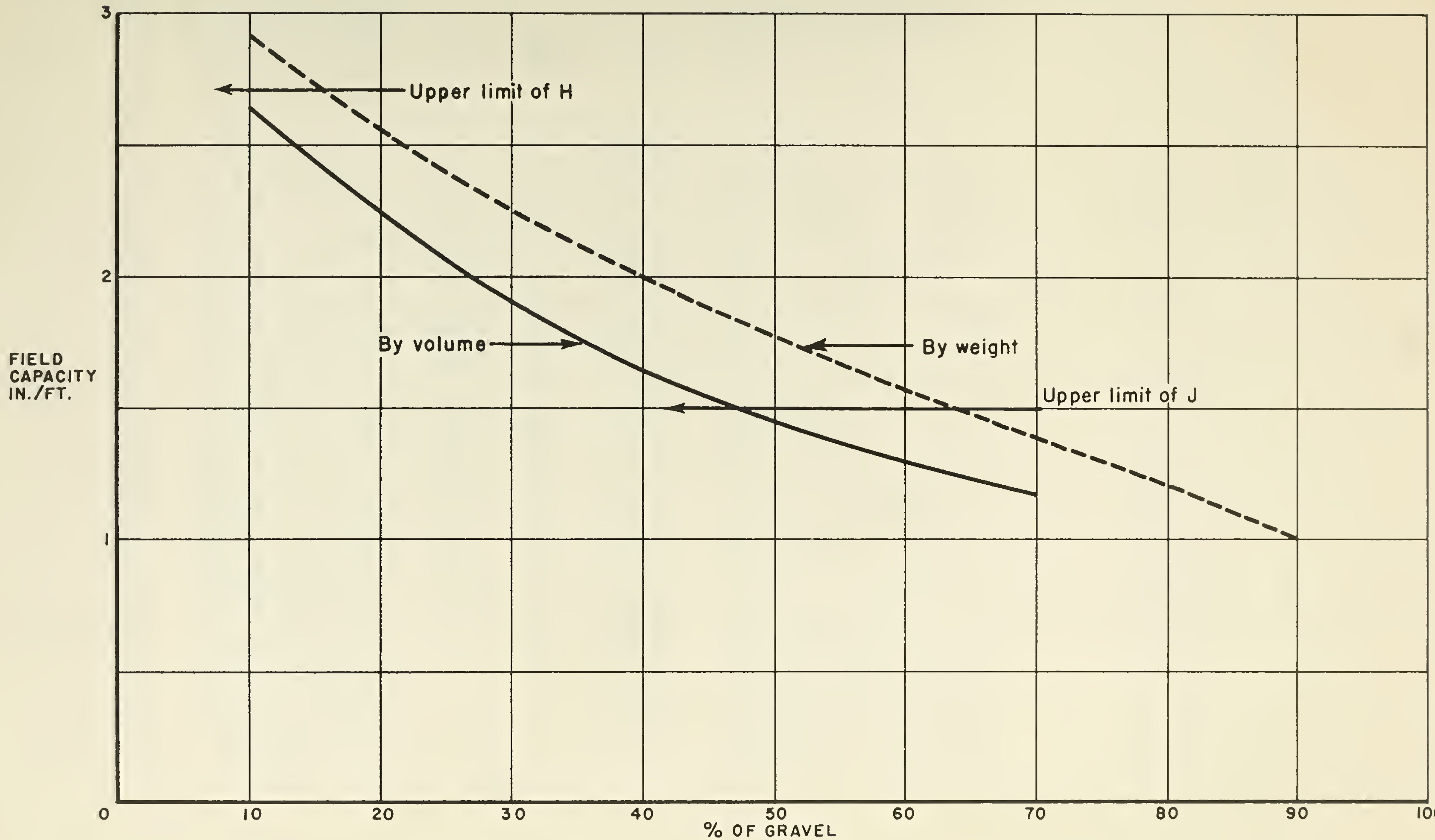

Figure 2. Relation between field capacity and volume of gravel (—) and weight of gravel (– –) for gravelly medium textured and gravelly light textured materials. Field capacities of H range from 1.5 to 2.7 in/ft whereas field capacities of J are less than 1.5 in/ft. Timpanogas Soil Conservation District.

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the soil. Thus, the tiling spade has only a limited value for estimating soil moisture.

Results similar to those obtained with the tiling spade were obtained with a penetrometer equipped with a 200 pound spring and a tube from an Oliver auger. The penetrometer appears to have the same limitations as the tiling spade for estimating readily available moisture.

Grouping Soil Units by Moisture Use

The value of readily available moisture used in Tables 1 and 2 were derived from the surface foot. Owing to the concentration of roots in the surface foot and, to some extent, to evaporation, the highest values of readily available moisture occur in the surface foot. Since the number of roots usually decreases with depth, especially below the second foot, the amount of moisture used at the time plants begin to show stress also decreases with depth. Thus the volume of water used to maintain rapid growth will vary with both the depth of soil and the type of root system. To reduce confusion, we will use the terms used by Metcalf (Part IV, Section A, Irrigated Land, Technical Guide, Salt Lake City, February 1951.):

MUD - Moisture used during maximum growth by deep rooted crops. The soil moisture is at field capacity to begin with and goes to the level where plants show stress.

MUS - Moisture used during maximum growth by shallow rooted crops.

CAM - This value represents the total capacity for available moisture in a given profile.

Actually, MUD represents the readily available moisture used by alfalfa to a depth of five feet. MUS represents the readily available moisture used by row crops, small grains and grasses to a depth of three feet. Remember that these figures cannot be precise when applied to farming operations, owing to variations within soil units, climatic differences and factors affecting both the depth and density of rooting. Therefore, the author prefers the term rapid growth to either maximum or optimum growth.

<u>MUD - Moisture used during rapid growth by deep rooted crops</u>

<u>such as alfalfa</u>:

MUD is the moisture use figure that is used along with other factors in subgrouping soil units and determining maximum land use capability. MUD is calculated for the 0 - 5 foot depth using the figures shown in Table 3. Note that most of the moisture is used from the 0 - 2 foot depth. Furthermore, that differences in texture which are very important in the 0 - 2 foot depth become less important below that depth.

Table 3: Moisture use values for alfalfa expressed in inches per foot by depth for different textures and materials:

Texture or Materials	Moisture Use (MUD) 0-1'	1-2'	2-3'	3-4'	4-5'
1,2,$\overline{3}$,3	2.1	1.8	0.9	0.6	0.6
4,03,H,K,L,G,C[a]	1.2	1.2	0.6	0.4	0.4
5	1.0	1.0	0.6	0.4	0.4
P,J,$\overline{0}$3	0.7	0.6	0.4	0.2	0.2
A,B,E,F,M,N	0.0	0.0	0.0	0.0	0.0

a. C materials below the upper foot in which they occur should be included with E.

If either the subsoil or substratum is stratified, use one of the following methods:

a. Quickie method - use the dominant texture in each foot.

b. Detailed method - multiply the appropriate value for each depth in Table 3 by the fraction of the foot represented by that texture or material.

Examples of calculating moisture use (MUD) for typical profiles are as follows:

Soil Unit 33J1

Depth Feet	Texture	MUD Inches
0 - 1	3	2.1
1 - 2	3	1.8
2 - 3	3	.9
3 - 4	3	.6
4 - 5	J	.2
		5.6

Soil Unit 4351

Depth Feet	Texture	MUD Inches
0 - 1	4	1.2
1 - 2	5	1.0
2 - 3	5	.6
3 - 4	5	.4
4 - 5	5	.4
		3.6

Soil Unit 14A3

Depth Feet	Texture	MUD Inches
0 - 1	1	2.1
1 - $1\frac{1}{2}$	4	.6
$1\frac{1}{2}$ +	A	.0
		2.7

In Figure 3 you can see the relation between MUD values and the range in depth to inhibiting layers. This helps to point out the limitations of the shallow soils. For example, a 34P3 could vary from 3.1 to 3.8 inches in the volume of moisture use by alfalfa at time of stress (MUD) owing to differences in depth to the P material. Further study of Figure 3 shows that MUD values for a 33P3 soil could vary from 3.3 to 4.3 inches. Thus, the shallower 33P3 soils are similar to 34P3, whereas the deeper 33P3 soils (when P occurs at a depth of 18 inches) are similar to 34P2 in moisture use. In mapping soil units underlain by inhibiting layers, Figure 3 indicates the similarity of moisture use (MUD) for many soil units.

In preparing the following classes of moisture use as a guide, such values are one of the factors in determining maximum land use capability of irrigated lands:

Moisture Use Class (MUD)	(0 - 5') Inches	Maximum Land Use Capability Class
Excellent	5.0 - 6.0	I
Good	4.0 - 5.0	II
Fair	3.0 - 4.0	III
Droughty	2.0 - 3.0	IV
Very Droughty	2.0	VI and VII

For example, if these criteria are used, soil units falling into moisture use class 3.0 - 4.0 inches would never have a maximum land use capability class higher than III. Other factors might change the capability class downward to IV or even to VII. Such soils could not have a capability class of either I or II owing to limitations of moisture capacity. In some areas where the climate is either cool, as in the high mountain valleys, or hot, as in southern Arizona, some adjustment upward or downward may be needed.

MUD values are also helpful in designing irrigation systems to insure adequate penetration and high irrigation efficiencies for deep rooted crops such as alfalfa. For example, you would plan to irrigate a 4551 soil so that you could fill the soil with four inches of water to maintain rapid growth of alfalfa. MUD values indicate the average depth of water required for alfalfa per irrigation to maintain rapid growth.

<u>MUS</u> - <u>Moisture use during rapid growth by row crops, small grains and grasses:</u>

MUS values are helpful in showing the relatively small quantity

of water needed to fill the root zone when those crops begin to show stress. Most row crops require a higher moisture level than alfalfa. You can see in Figure 3 that from 2 to 3 inches of water will fill the root zone of most row crops when rapid growth is maintained. MUS values are based on the 0 - 3 foot depth, assuming that the effective depth has been brought to field capacity prior to planting[2].

In the case of potatoes, celery and possibly other truck crops, in order to maintain rapid growth, it may be desirable to irrigate when even less water has been used by the crop than indicated in Table 4. The primary value of MUS is to show the need for designing irrigation systems to avoid heavy leaching irrigations of row crops, small grains and pasture. This is especially important in border irrigation.

Table 4: Moisture use values for row crops, small grains and grasses, expressed in inches per foot by depth for different textures and materials.

Texture or Materials	Moisture Use (MUS) 0 - 1'	1 - 2'	2 - 3'
1, 2, $\overline{3}$, 3	1.4	0.9	0.9
4, 03, H, K, L, G, C[a]	1.0	0.6	0.6
5	0.8	0.6	0.6
P, J, $\overline{0}$3	0.5	0.4	0.4
A, B, E, F, M, N	0.0	0.0	0.0

a. Except for the first foot of C materials, they should be included with E.

To calculate MUS values, use the appropriate value for each texture or material corresponding to the depth at which it occurs, Table 4.

2. Note that the values used in Table 4 for the first foot are lower than those used by Metcalf. The writer furnished the data used by Metcalf but further studies indicated that the values used in the surface foot were too high except for grass seed production prior to emergence of heads.

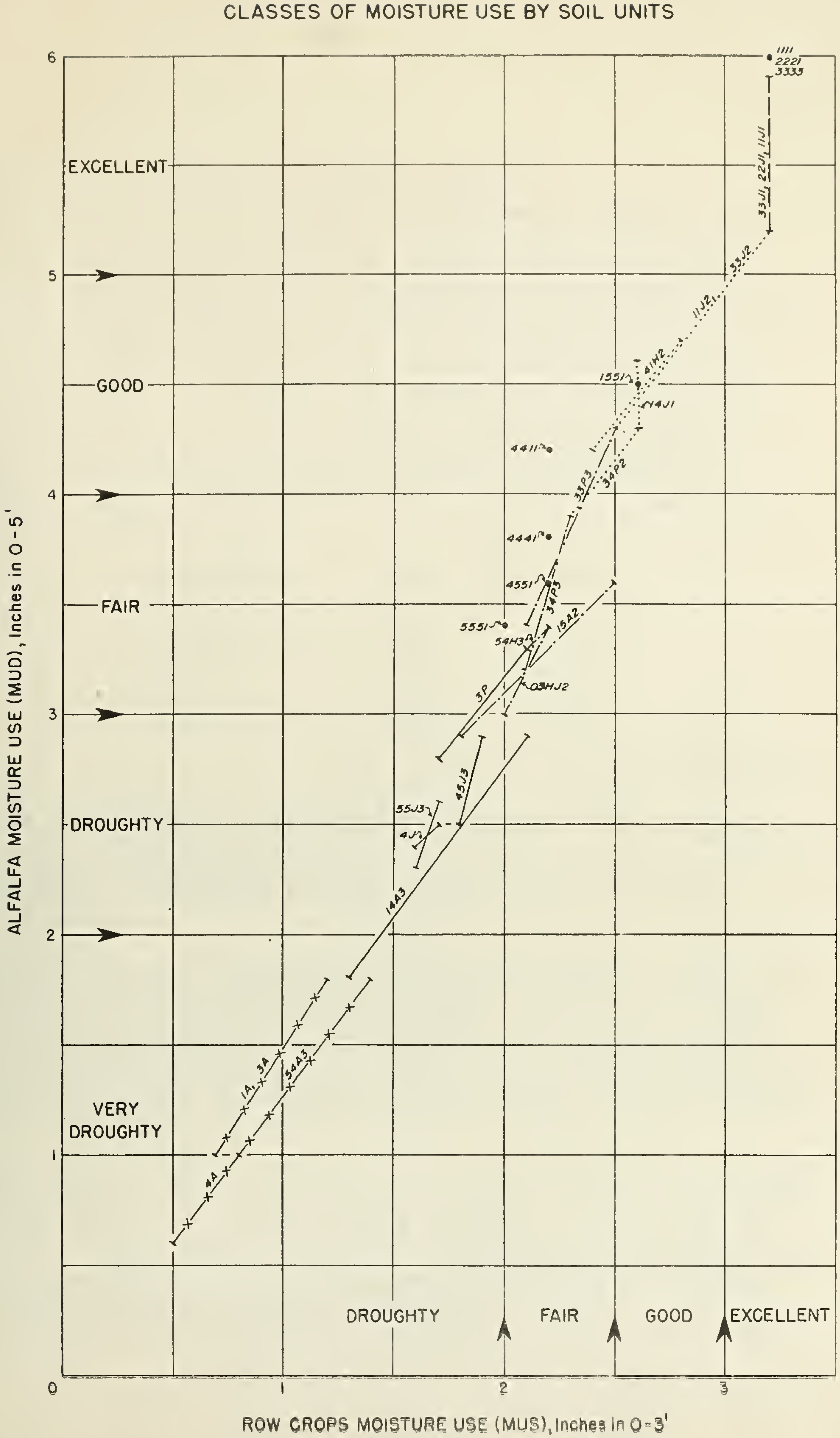

Figure 3. Relation between soil units and moisture use during rapid growth. Very shallow soils are assumed to be 6-10 inches deep, surface soil of shallow soils from 8-12 inches deep, all others 12 inches deep. J is assumed to occur under H in very shallow soils at 30 inches, in shallow soils at 42 inches, and in moderately deep soils at 48 inches.

CAM - Total capacity for available moisture:

CAM is useful in areas of water shortage where crops have been forced to exhaust the available soil moisture, also in many cotton areas where the cotton is allowed to exhaust the available moisture in order to hasten maturity. CAM values are helpful in designing an irrigation system where such practices occur. They are calculated from Table 1. To calculate the CAM value, use the readily available moisture value from the surface foot and multiply by the depth of the texture that you wish to fill. For soil unit 3331, it would be 2.1 x 5 equals 10.5 inches to bring the 0 - 5 foot depth to field capacity. If you have soil units with horizons of different textures, always use the maximum values assigned the surface foot for that texture (i.e.) soil unit 14Pl.

Depth Feet	Texture	In/Ft
0 - 1	1	2.1
1 - 2	4	1.2
2 - 3	4	1.2
3 - 4	4	1.2
4 - 5	P	.7
		6.4 inches required.

There is a possibility that the CAM value for certain clays may be low. However, our data indicate that plants fail to extract some of the moisture held just above wilting point. This may be due to roots being less abundant in many clay subsoils and substrata.

Consumptive use: In planning the water requirements for the entire growing season, Blaney and Criddle (2) have summarized consumptive use data for different crops. Thus, one can calculate the total amount of water required for each crop if the ditch loss, surface waste water and deep percolation losses are known. The annual consumptive use coefficients, K, for different crops are helpful in estimating annual consumptive use.

Unfortunately, monthly consumptive use coefficients, k, are less well established. For example, the k values tend to be too high for a row crop in its early stages of growth. Other k values need to be more firmly established. During the spring months at the Albuquerque Nursery early growing grasses had a k value of .87 whereas the warm weather growers had a k value of .54. For the western states, Blaney and Criddle report that the K value

for grass, pasture and hay is .75. If you need to know how much water should be applied for a given irrigation, consumptive use values should be supplemented by field estimates of the moisture required, using the ball test. This does not minimize the value of annual consumptive use coefficients but does point out the need for more work, supplemented by soil moisture studies, before trying to use monthly consumptive use coefficients.

Temporary Storage

Definition: The volume of temporary storage is equal to the total pore space minus field capacity, expressed as inches depth per foot depth of soil. We are concerned with the volume of temporary storage that can be filled during either an irrigation or a rain because it influences the depth within which limiting layers can affect intake rates.

For practical purposes, total pore space can be calculated from volume weight data, assuming that the specific gravity is 2.65, using the following formula:

$$\text{Total pore space in/ft} = \left(1 - \frac{\text{Volume weight}}{\text{Specific gravity}}\right) \times 12.$$

$$\text{Total pore space in/ft} = (1 - .377 \text{ volume weight}) \times 12.$$

Degree of Compaction: Since the degree of compaction within a textural class determines the volume of temporary storage, three degrees of compaction are shown in Table 5. The volume weight limits of the degrees of compaction are based on permeability data from 2000 Uhland core samples supplemented by irrigation intake rates. The volume weight limits of compaction are similar for fine, moderately fine and medium textured soils containing more than 40% silt. The remaining textural classes have separate limits of compaction.

Within a textural class, the degree of compaction determines the volume of temporary storage. See in Figure 4 that compacting a clay loam from a volume weight of 1.25 to 1.50 cuts the temporary storage in half. Since the volume weight of the surface soil within a textural class is determined principally by tillage practices, it is important to determine the range of moisture suitable for safe tillage. In addition, we need to know if subsoils which are compact, owing to processes of weathering and deposition, can retain increased temporary storage if they are deep tilled.

TWICE AS MUCH TEMPORARY STORAGE IN FIRM SOILS THAN COMPACT SOILS

One Cubic Foot Of Clay Loam

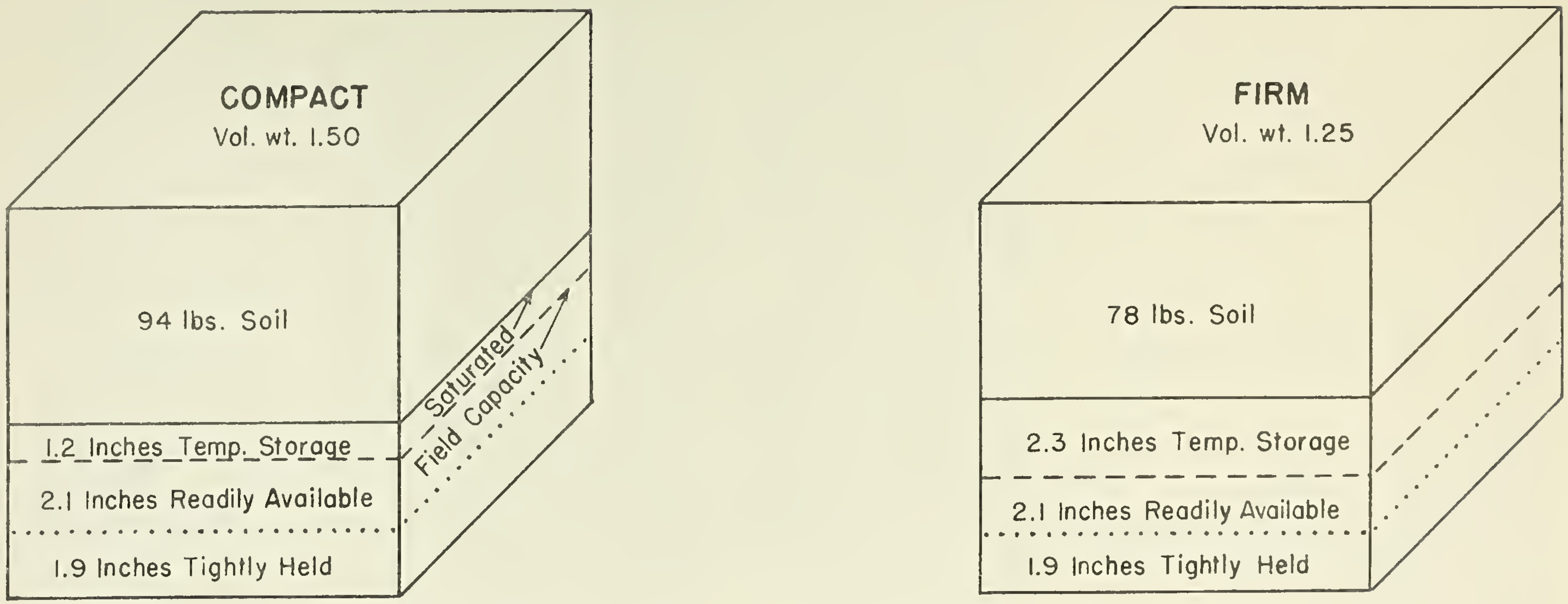

Figure 4. Lack of temporary storage (pore space above field capacity) as well as reduced intake rates render compact clay loams subject to serious runoff and erosion losses.

Table 5: Volume weight classes listed by texture and degree of compaction for non-gravelly soils (Tentative.)

Texture	Firm	Degree of Compaction Moderately Compact	Compact
1 Fine	-1.25	1.26 - 1.45	1.46+
2 Moderately fine	-1.25	1.26 - 1.45	1.46+
$\bar{3}$ Medium (40%+ silt)	-1.25	1.26 - 1.45	1.46+
3 Medium (0-39% silt)	-1.41	1.42 - 1.52	1.53+
4 Moderately coarse	-1.45	1.46 - 1.64	1.65+
5 P Coarse	-1.55	1.55 - 1.75	1.76+

Interrelation of texture, field capacity and temporary storage: Since temporary storage is equal to the total pore space minus field capacity, there is usually much less temporary storage in fine textured soils than in coarse textured soils. This is true because field capacity increases with fineness of texture and because total pore space is the same for soils with similar volume weights. Study Figure 5. A 1 texture has but .2 in/ft temporary storage when the volume weight is 1.50, whereas a 5 texture has 3.6 in/ft of temporary storage.

How much temporary storage is there in different textures by classes of compaction? As explained on Page 4, we found that field capacity values are similar for different degrees of compaction within a textural class when expressed on a volume basis, in/ft. Table 6 has been calculated, using average field capacities for each texture. The temporary storage in a firm, coarse texture (Table 6) is from three to four times the total volume of readily available moisture (Table 1.) Even in a firm clay loam, the temporary storage, 2.3 in/ft., may exceed the volume of unfilled readily available moisture, 2.1 in/ft at time of stress. On the other hand, there is very little temporary storage in compact, fine textured soils.

What percentage of temporary storage is filled during average irrigations? We found that over 50% of the temporary storage remained filled for an hour on medium textured soils which had intake rates in excess of five inches per hour. Unfortunately, we have to rely on other sources of information for soils with lower intake rates. The author has taken many soil moisture samples from 10 to 30 minutes after applying the second two inch storm on dry farm lands with an infiltrometer (5.) At that time,

half of the temporary storage remained filled in soils possessing an average intake rate in excess of one inch per hour. In contrast, 80% of the temporary storage remained filled in soils possessing average intake rates appreciably less than one inch per hour. In these cases, tillage pans were the limiting layers. Undisturbed cores allowed to remain overnight in a tank of water have been found to have practically 100% of the temporary storage filled. Based on these data, 90% of the temporary storage may be filled above a limiting layer during an average irrigation of 3 to 5 inches of water, when the intake rate is less than one inch per hour.

Table 6: Relation between temporary storage, texture and degrees of compaction expressed in inches per foot:

Texture	Average Field Capacity	Temporary Storage Firm	Moderately Compact	Compact
1 Fine	5.0	1.3+	0.4 - 1.3	.0 - 0.4
2 Moderately fine	4.0	2.3+	1.4 - 2.3	.0 - 1.4
$\bar{3}$ Medium (40%+ silt)	3.7	2.6+	1.7 - 2.6	.0 - 1.7
3 Medium (0 - 39% silt)	3.2	2.4+	1.9 - 2.4	.0 - 1.9
4 Moderately coarse	2.2	3.2+	2.4 - 3.2	.0 - 2.4
5 Coarse	1.6	3.4+	2.4 - 3.4	.0 - 2.4

<u>Relation between temporary storage and depth to limiting layer</u>: By determining the minimum depth required to hold temporarily a 3 inch irrigation, we can estimate the depth which includes the layers affecting irrigation intake rates. In Figure 6, 90% of the temporary storage is assumed to be filled during an average irrigation. With 1/4 readily available moisture present prior to irrigation, a three inch irrigation could be temporarily stored in the surface foot of all textures which are firm. Even compact 3, 4 and 5 textures could hold a three inch irrigation within the surface foot. In contrast, compact, moderately fine and fine textures require appreciable portions of the second foot to temporarily store such irrigations. So, layers limiting intake rates from three inch irrigations appear to be confined to the surface foot, except in compact, moderately fine and fine textures.

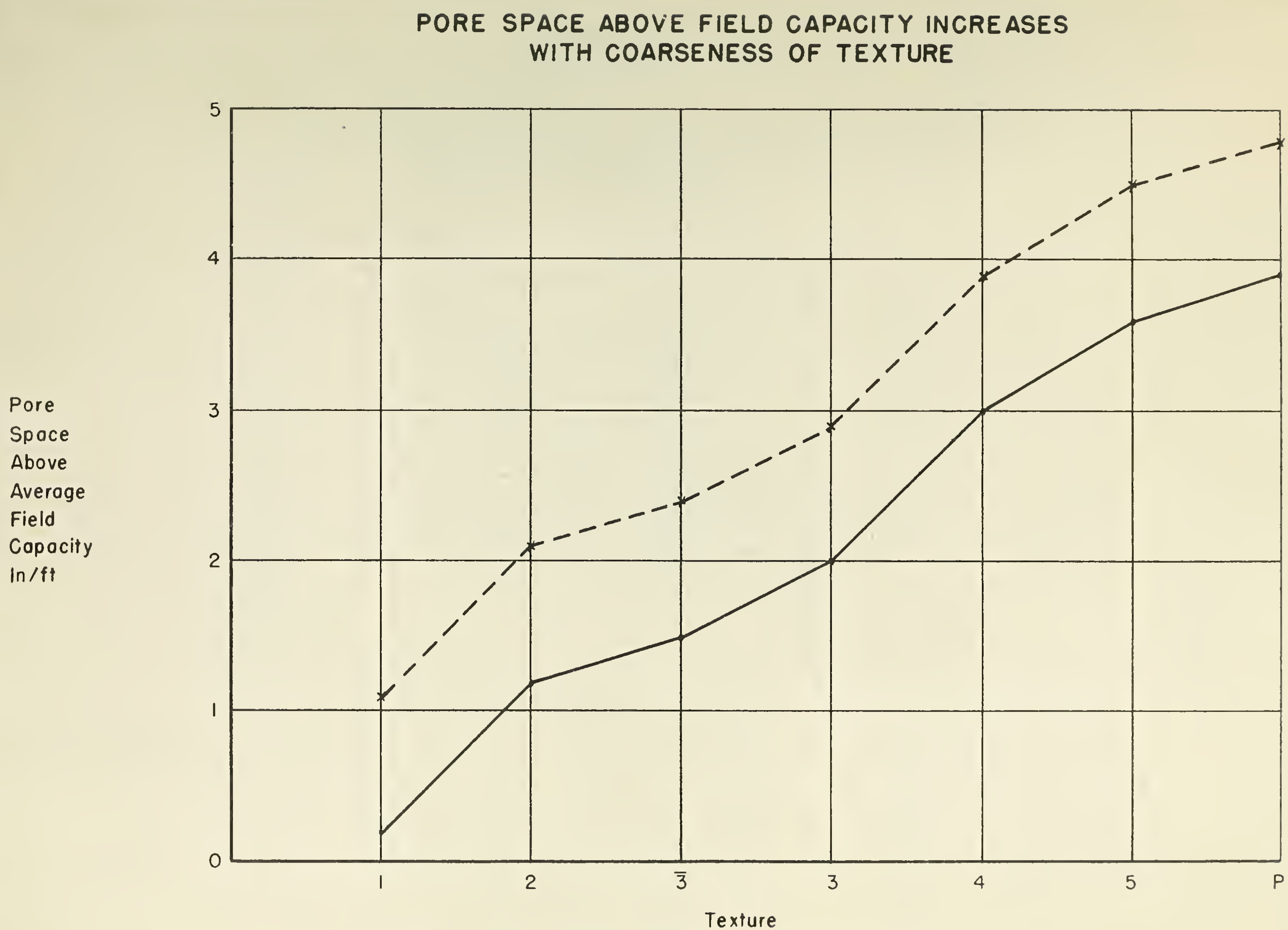

Figure 5. Pore space, inches per foot above field capacity by texture when the volume weight is 1.50 (——), 1.30 (– –).

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COMPACTION INCREASES MARKEDLY MINIMUM DEPTH REQUIRED TO HOLD TEMPORARILY 3-5 INCH IRRIGATIONS IN MODERATELY HEAVY AND HEAVY SOILS.

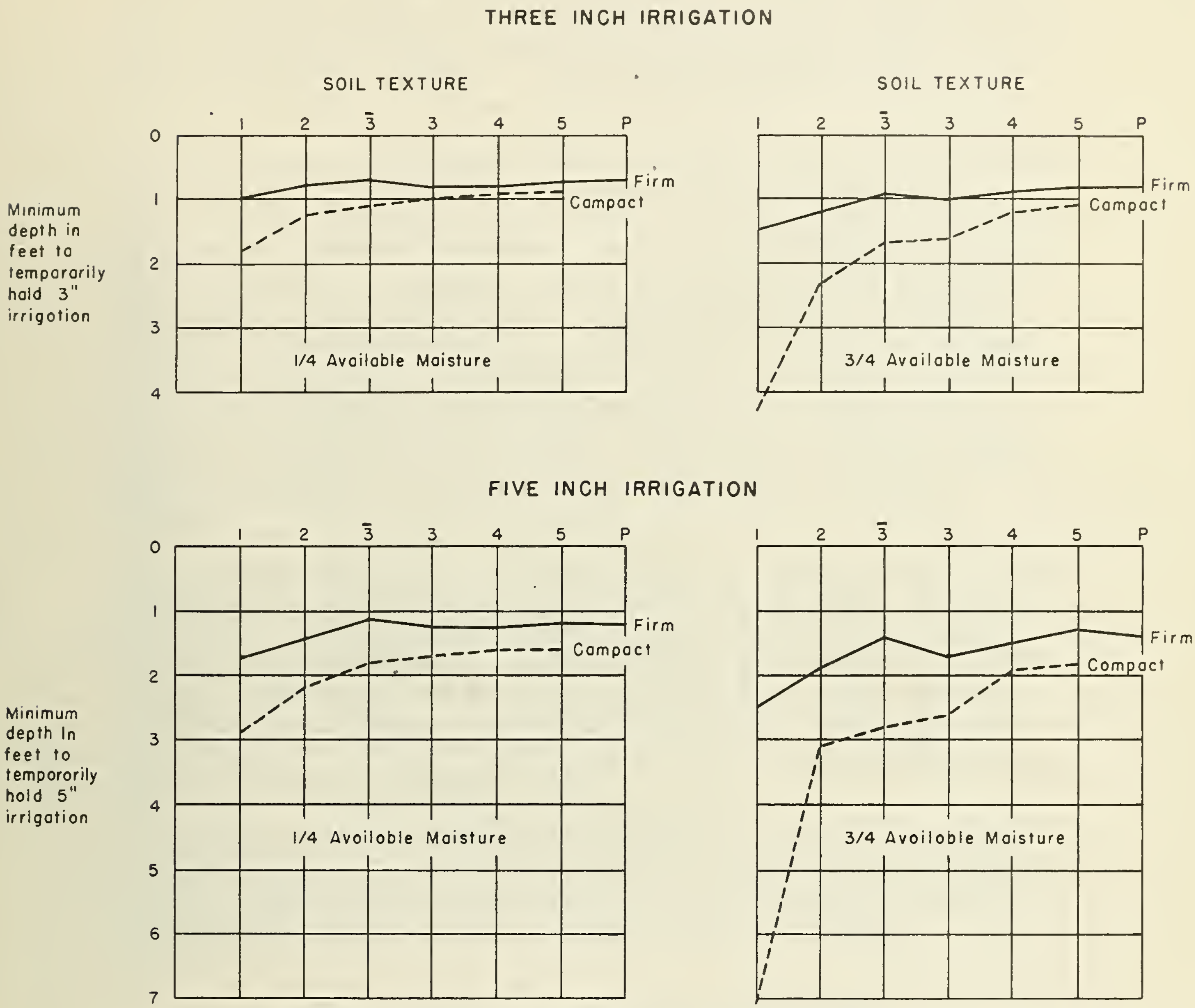

FIGURE 6. Minimum depth of soil by textural groups required to hold temporarily 3 inch and 5 inch irrigations for different moisture contents and compaction classes.

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Next, let us calculate the minimum depth of soil required to temporarily store a five inch irrigation when 1/4 readily available moisture is present. Such a depth could be stored temporarily in the 0 - 15 inch depth of medium to coarse textures when they are firm. If compact, approximately 20 inches of these soils would be required to temporarily store a five inch irrigation. In contrast, more than two feet of compact 1 and 2 textures would be required. Layers limiting the intake rate of five inch irrigations occur principally in the 0 - 2 foot depth.

In the preceding paragraphs we have assumed that the irrigations were made when 1/4 readily available moisture was present but, occasionally, irrigations may be made when 3/4 readily available moisture is present. In compact soils at this moisture content, fine soils require a minimum depth of 50 inches to temporarily hold a three inch irrigation. Similarly, 20 inches of medium textured soils would be required and only 13 inches of a coarse textured soil would be required, Figure 6. Soil layers affecting average irrigation intake rates would occur within these depths. In firm soils, the depth required to temporarily hold a three inch irrigation is less and, accordingly, limiting layers affecting irrigation intake rates occur within a shallower depth.

Temporary storage values can also be used to estimate the volume of water to be drained when water tables are present, Table 6. For example, a moderately compact, coarse textured soil would contain from 2.4 to 3.4 inches per foot of free water. In contrast, a moderately compact, fine textured soil would contain only 0.4 to 1.3 inches per foot of free water. To lower the water table one foot would result in draining several times as much water from the coarser soil.

Conversely, in areas where water tables are present, temporary storage values can be used to illustrate that the same volume of deep percolation from over-irrigation will raise water tables faster on the finer textures than the coarser textures.

Factors Affecting Irrigation Intake Rates

Moisture prior to irrigation: Contrary to popular belief, a wide range in moisture present prior to irrigation was a minor factor affecting average border irrigation intake rates (Figure 7.) Most irrigations are made when the readily available moisture in the surface foot varies from 0 to 3/4. Separating

intake rates by percentages of available moisture present in the surface foot failed to indicate that differences in moisture in this range affected intake rates of medium to fine textured soils. Two explanations are offered: Soils which crack upon drying usually have large cracks by the time the readily available moisture is reduced to 3/4. The relatively large volume of temporary storage in many soils is adequate to maintain intake rates so that differences in volume of readily available moisture are minimized.

At readily available moisture contents above 3/4 however, average border irrigation intake rates are appreciably reduced in fine textured soils. For example, at the Albuquerque Nursery, a clay soil was irrigated in order to apply phosphoric acid for grass seed production, when the readily available moisture in the surface foot was between 3/4 and field capacity. The average irrigation intake rate was .5 in/hr. In contrast, the average irrigation intake rate was 1.8 in/hr for the next irrigation when the surface foot was allowed to dry to 0 - 1/4 readily available moisture.

We just concluded that the range of 0 - 3/4 readily available moisture in the surface foot was a minor factor affecting average irrigation intake rates from border irrigations. Likewise, differences in moisture content prior to irrigation appear to be a minor factor affecting average furrow irrigation intake rates (Figure 8.) Furrow irrigation infiltration data for corn reported by Mech (13) indicate also that differences in moisture content prior to irrigation were minor in determining intake rates.

<u>Compaction within a textural class</u>: Degree of compaction of the limiting layer in the surface foot is <u>one of the most important factors</u> influencing intake rates within a textural class (Figure 9.) For example, at the Albuquerque Nursery, there were two clay fields which were border irrigated when 0 - 1/4 readily available moisture was present, the cracks at the surface were fully 1/2 inch wide. One field was compact; the intake rate was but .2 in/hr. The other field was moderately compact (approaching firm;) the intake rate was 1.8 in/hr. Free-hand curves have been drawn in Figure 9 showing strong trends between irrigation intake rates and compaction for 1, 2, 4, 03 and 5 textures.

Border irrigation intake rates for 3 textured soils tilled since the last irrigation are also related to compaction but there is little correlation for such soils which were not tilled since

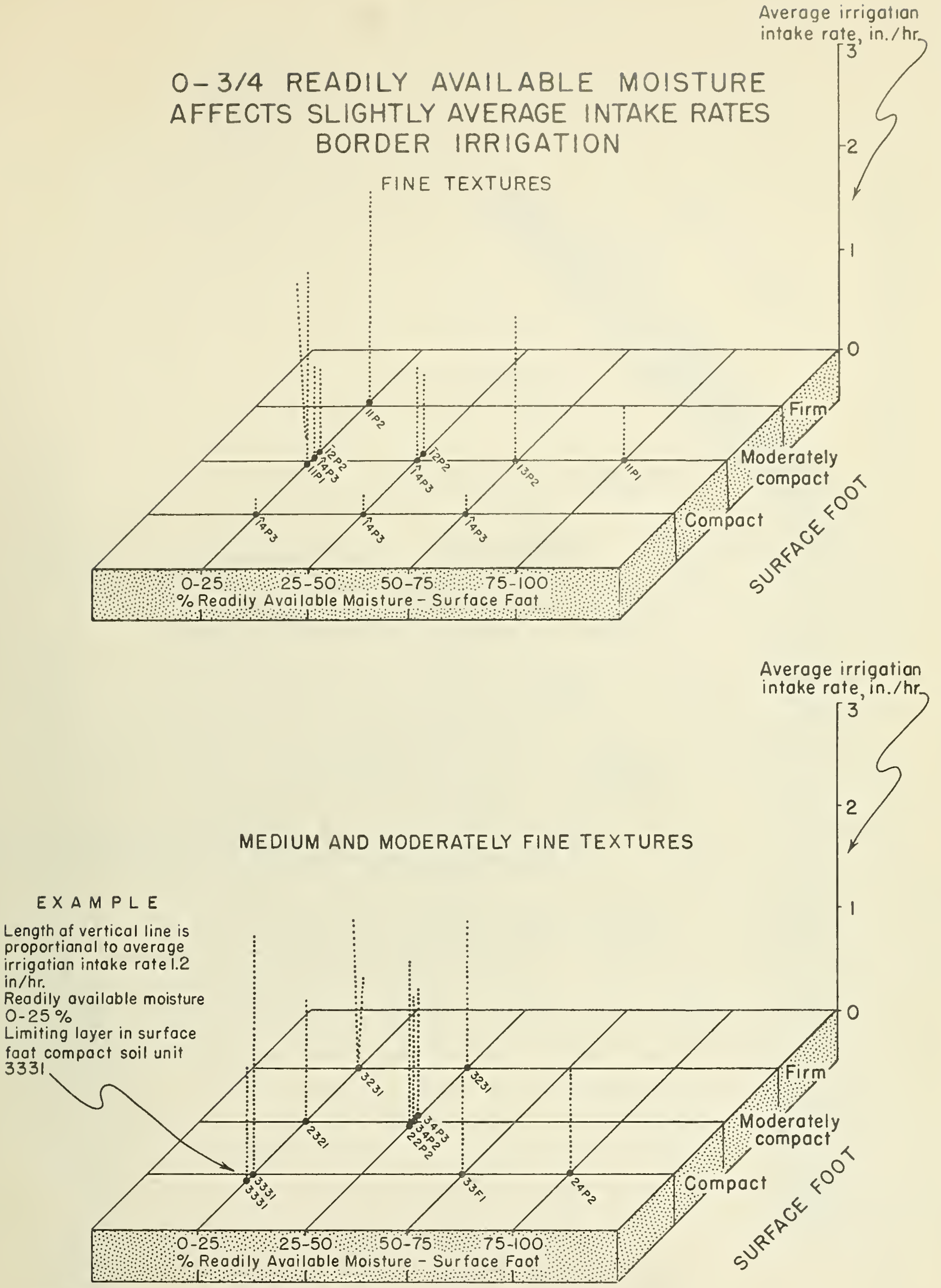

Figure 7. Relation between average irrigation intake rate for borders, compaction of limiting layer in surface foot, and % readily available moisture in surface foot for borders irrigated prior to last tillage by soil units in New Mexico and Arizona.

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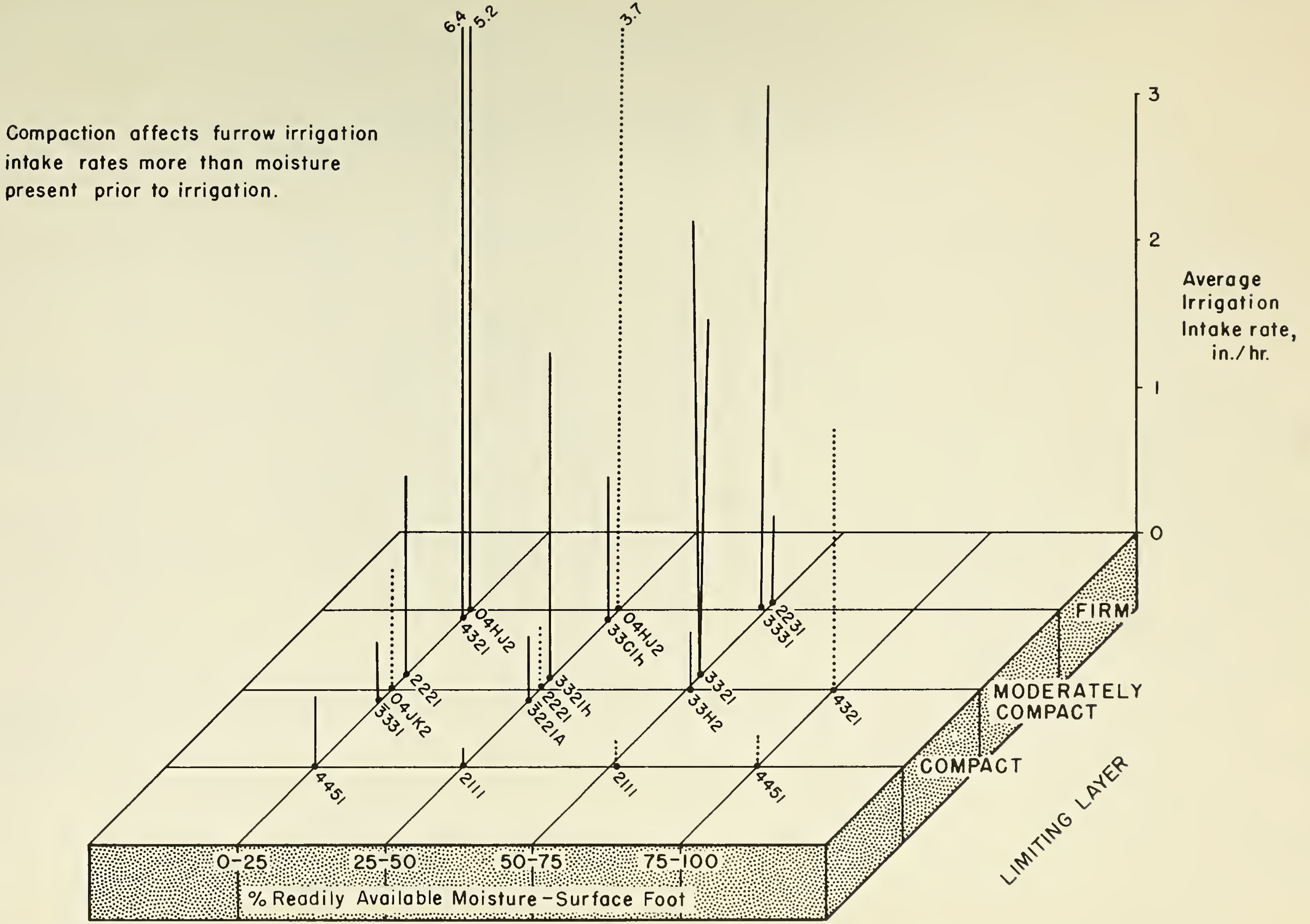

FIGURE 8. Relation between average furrow irrigation intake rate, compaction of limiting layer, and % available moisture in the surface foot for fresh tilled (——) and irrigated prior to last tillage (·····) by soil units in Colorado, New Mexico and Utah.

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COMPACTION REDUCES IRRIGATION INTAKE RATES

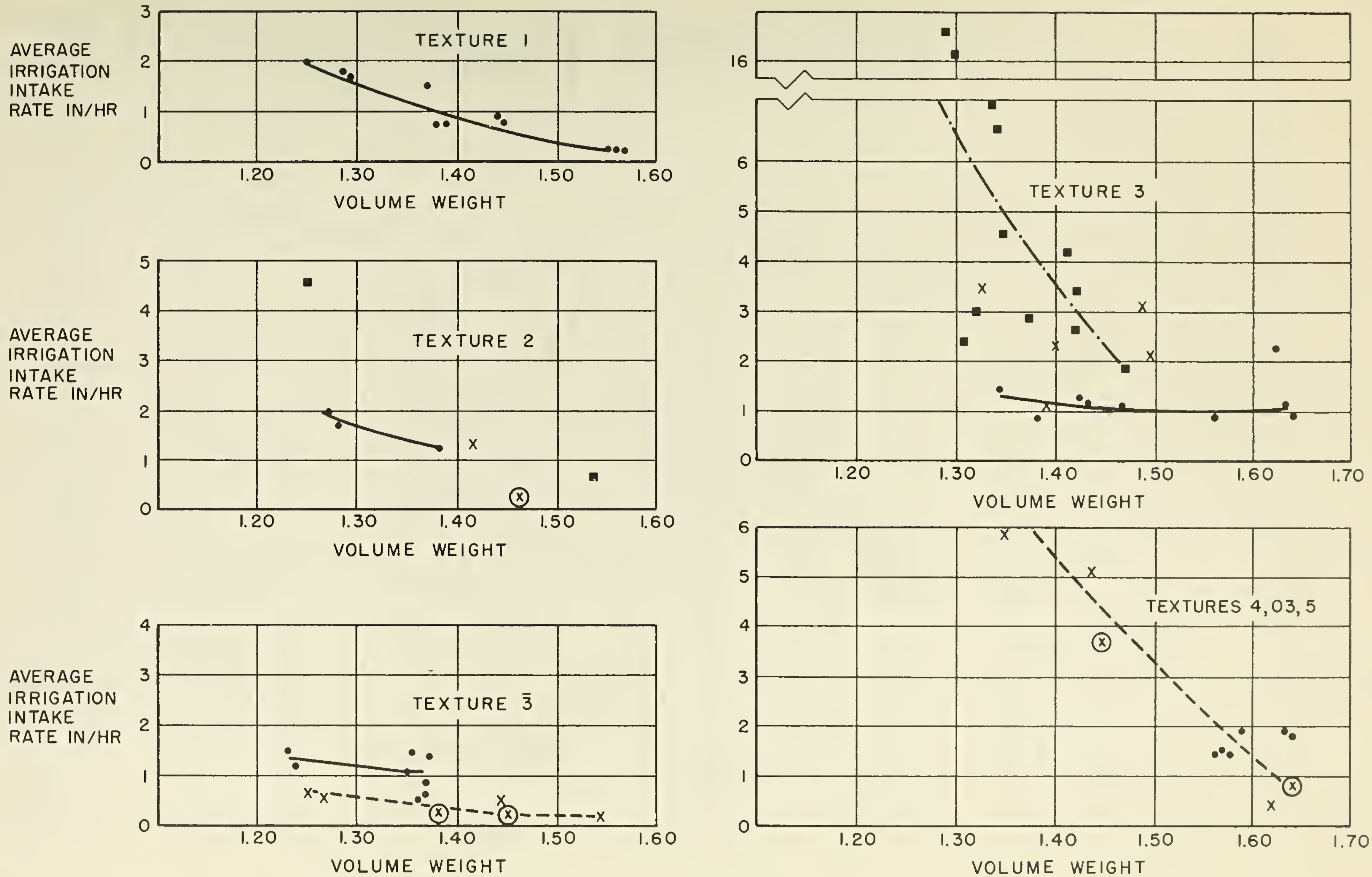

Figure 9. Relation between volume weight of the limiting layer in the surface foot by soil texture and average irrigation intake rates in Arizona, Colorado, New Mexico, and Utah. Border irrigations: tilled since last irrigation (■)(—·), not tilled since last irrigation (•)(—); furrow irrigations: tilled since last irrigation (x)(– –), not tilled since last irrigation (ⓧ). The available moisture in the surface foot prior to irrigation varied from 0–3/4.

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last irrigation. This may be chance, since the compact soils contained more effective pores than the firm and moderately compact soils within this texture class.

Furrow irrigation intake rates were less than one inch per hour on unstable $\bar{3}$ textured soils; the rates decreased as compaction increased. There was, however, little correlation between compaction and border irrigation intake rates on the $\bar{3}$ textured soils studied. The intake rates which upset the relation are from a soil containing 40% silt, the dividing line between $\bar{3}$ and 3 textured soils. Compacted layers within the surface foot appear to be one of the most important factors determining average irrigation intake rates.

Compaction by farm machinery may reduce intake rates markedly. For example, at the Albuquerque Nursery, soil unit $\hat{1}$4P3, tall wheatgrass in 3' rows, had an average intake rate of .9 in/hr in 1948 (Figure 10.) In the spring of 1949 a tractor with a buck rake was used to remove old hay following a series of light snows. The resulting compaction reduced the intake rate to .2 in/hr in 1949. Chiseling the clay soil to break the tillage pan in the fall of 1949 failed to increase the irrigation intake rates in 1950. Furrow intake rates as low as .2 in/hr have been observed also in compacted sandy loam soils. Compaction caused by farm machinery may be an important factor in reduced irrigation intake rates and the cause of inadequate penetration.

Compaction of medium textured surface soils by farm machinery also reduces irrigation intake rates (cover page.) A field which had been in cotton for 3 years was chiseled and plowed in March. In this rough, cloddy condition, the average irrigation intake rate was 7.0 in/hr. Following 6 cultivations, the intake rate dropped to 1.8 in/hr for the next irrigation in June. Part of this decrease is attributed to compaction caused by cultivating when the soil contained more than 1/2 readily available moisture (durable balls.)

Compaction may cause slow intake rates on soils normally considered highly permeable, such as gravelly, medium textured soils. Near Provo, Utah, we studied a pear orchard on .8% slope, soil unit 03JK3. Owing to a tillage pan, moisture penetration was inadequate following a three-hour furrow irrigation. The intake rate was 0.8 in/hr. So, be careful how you use implements causing compaction.

<u>Tillage of stable soils</u>: Figures 8 and 9 show that tillage of stable soils often increases the average irrigation intake rate as compared with irrigations on areas which have not been tilled

since the last irrigation. If the tillage operation does not cause appreciable compaction, intake rates of medium textured soils following tillage are often an inch per hour faster than that of succeeding irrigations without tillage. Tillage, at moisture contents when the soil will not make a durable ball, usually fluffs up the soil, increases the amount of temporary storage and increases intake rates, but tillage at moisture contents when the soil will make a durable ball usually creates a tillage pan and reduces intake rates.

Tillage of unstable soils: Cultivating a badly crusted cotton field when the surface soil would make a fragile ball, increased the average furrow irrigation intake rate from .39 to .47 in/hr on soil unit $\bar{3}221$ A near Lordsburg, New Mexico. Unstable medium textured soils frequently have low irrigation intake rates even when the soil is dry, rough and cloddy. Under these conditions, the average furrow intake rate was .41 in/hr at Deming, New Mexico, for a 12-hour preplanting irrigation on soil unit $\bar{3}331$ on a .2% grade (Figure 11.) This same area, in June, had a furrow irrigation intake rate of .08 in/hr on an uncultivated portion as compared with .21 in/hr on a cloddy, cultivated portion. The cloddy area was cultivated three days after an irrigation when the soil was still nearly at field capacity. Little compaction occurred as a result of this cultivation, owing to the high moisture content partially preventing the rearrangement of soil particles. At the Albuquerque Nursery, Figure 12, uneven filling of a chiseled unstable, medium textured silty soil occurred following the third irrigation. No tillage had occurred since chiseling prior to the first irrigation. Other investigators have reported reduced rates following tillage. Differences in compaction and ease of pulverizing at time of tillage may be the explanation. In general, tillage does not affect the intake rates of unstable soils in terms of inches per hour, because they are slow anyway. Practically, tillage may change appreciably the time required in hours for an adequate irrigation. For example, reducing the intake rate from 0.4 in/hr to 0.2 in/hr will double the time required for water to enter the soil.

Field method for estimating volume weights of 1, 2, $\bar{3}$ and 3 textures: A satisfactory method, using a snow tube balance was developed in 1951, for estimating volume weights of medium to fine textures. Volume weight data are useful in determining the degree of compaction in different layers which may affect intake rates of irrigation trials. On the spot service can be given to determine the need for chiseling and the proper depth of chisel-

INTAKE RATES REDUCED BY FARM MACHINERY COMPACTING CLAY SOIL

Date	4/13/48	4/29/49	8/1/50
Border size	36'x660'	36'x660'	36'x660'
Average flow, c.f.s.	2.1	1.5	1.2
Depth applied, inches	2.0	2.8	2.1
Average irrigation intake rate, in./hr.	0.9	0.2	0.2
Available moisture, 0-1'	1/4-1/2	1/4-1/2	1/2
Uniform grade, percent	0.1	0.1	0.1
Tall wheatgrass, height, inches	5	10	45

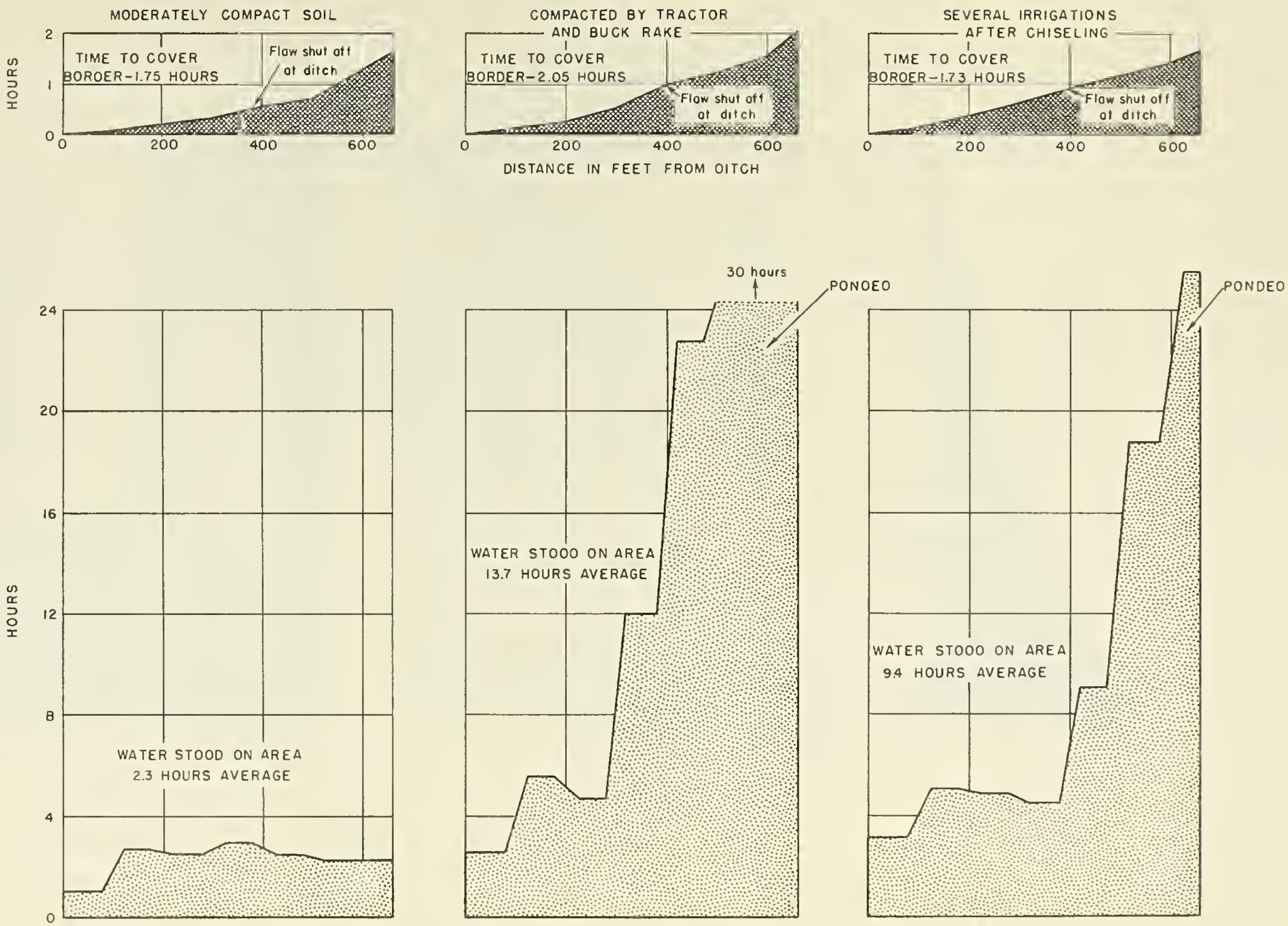

FIGURE 10. Border irrigation trials on tall wheatgrass, soil unit T4P3, Albuquerque Nursery. This compact silty clay was further compacted by a tractor in March, 1949, and was chiseled in November, 1949, to loosen the pan.

12 HOUR IRRIGATION FAILS TO FILL UNSTABLE SILTY SOIL, .2% VARIABLE GRADE

Date	3/22/51	Depth applied, inches	7.1
Soil unit	$\overline{3}331$	Waste water, inches	1.0
Area	102' x 630'	Average irrigation intake rate, in/hr.	.41
Furrow Spacing	36"	Readily available moisture surface foot	0-1/4
Average flow per furrow	17.2 g.p.m. for 0-1.8 hrs. 10.8 g.p.m. for 1.8-12.0 hrs.		

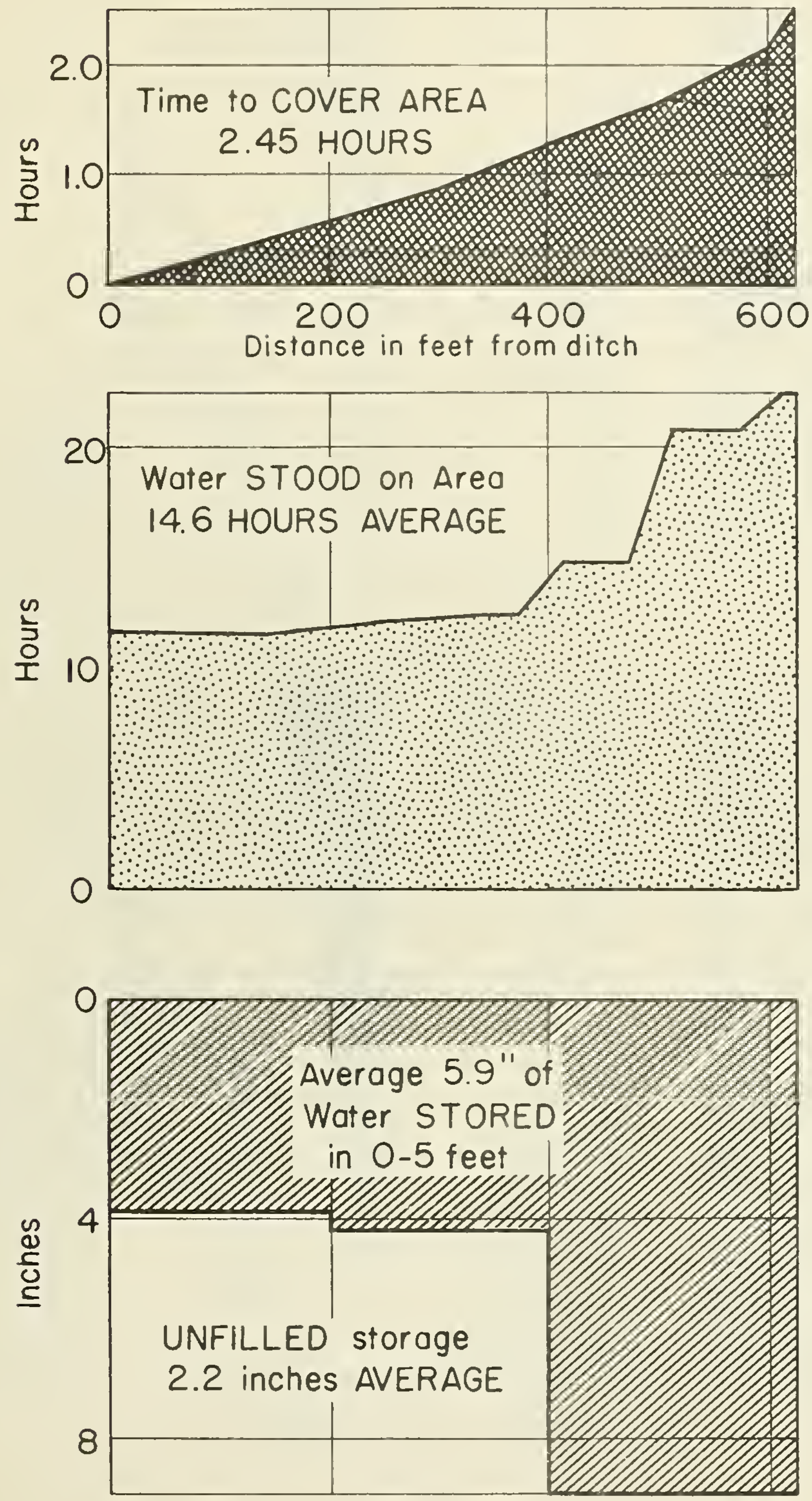

Figure II. Preplanting furrow irrigation trial on rough cloddy unstable silty surface soil, .2 % variable grade. Second season in cotton following two years of alfalfa on the lower three fourths of the area and five years of pasture on the upper fourth of the area. Oscar Goldsmith farm, Deming Soil Conservation District.

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UNEVEN STORAGE OF WATER IN THIRD IRRIGATION AFTER CHISELING DUE TO "MELTING" OF SOIL INTO CHISEL MARKS

	April 12	April 26
Border size 36'x 835', Slope 0.25 %		
Crop - Russian wild rye grass in rows 36" wide, height inches	12	
Average Flow c.f.s.	2.43	1.89
Depth applied, inches	2.7	2.1
Time applied, minutes	45	46
Average irrigation intake rate in/hr	0.8	0.8
Water table depth in inches	54	50
Tillage pan moderately compact	yes	yes
Available moisture prior to irrigation: 6-12 inches	1/4-1/2	1/4-1/2
Deep percolation loss, inches	.1	.3

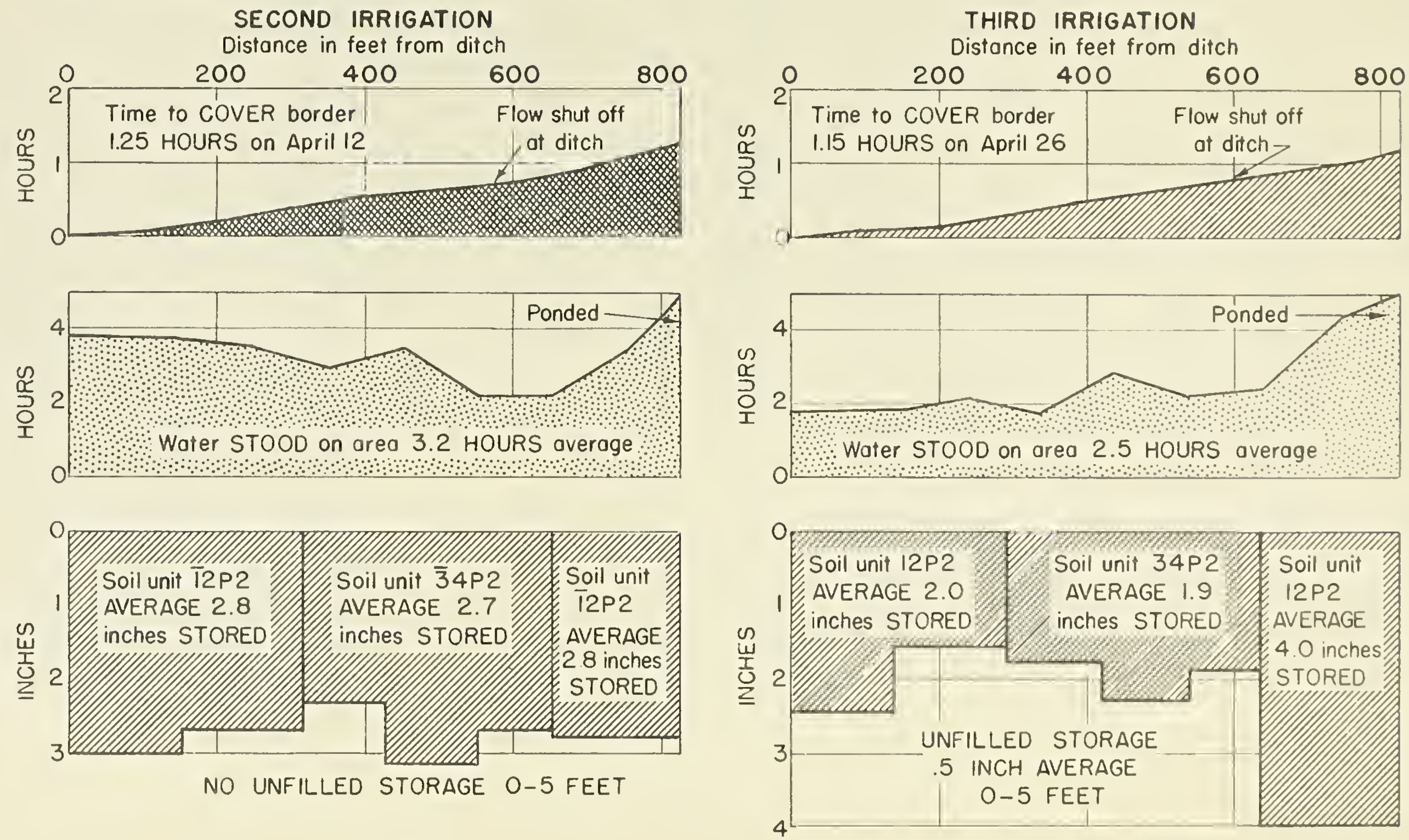

Figure 12. Border irrigation trials on soil units $\overline{1}$2P2 and $\overline{3}$4P2, Field I Border 18, Albuquerque Soil Conservation Sevice Nursery. April 1950.

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ing. Likewise, it can be used to determine if adequate compaction has been obtained in stock tanks. The procedure is as follows:

1. Determine the texture of the layer to be sampled.
2. Determine the % of readily available moisture, use Table 2.
3. Take two sets of 3 Uhland core samples in each layer sampled. Trim the samples to known volume, place a 4-3/4 inch square of muslin over bottom end and fasten with rubber band.
4. Place a set of 3 core samples immediately in a round dinner pail, with lid. (Weight of 3 empty cylinders, cloths, bands and pail 860 grams.)
5. Weigh the pail and the cores using a Mt. Rose snow balance designed for a 12-1/2 foot snow tube.
6. Enter the reading of the balance under the proper texture and % of readily available moisture in Table 7 and read directly the average volume weight for the 3 cores. Average the volume weight values for the two sets of cores.
7. If the texture is approaching that of another class, look up that value and interpolate.

To find the volume weight of a fine textured soil, using Table 7:

Texture 1:

% Readily available moisture	1/2
Snow tube scale reading	60.0
Estimated volume weight	1.25

During 1951, 158 comparisons of estimated versus actual volume weight were made in widely separated areas in Utah, Colorado, Arizona and New Mexico. In most of the areas, the author had not made any soil studies previously. 75% of the samples were estimated in the field within .05 of the oven dried volume weight. There was little difference in the estimates for different classes of moisture except those samples which were above field capacity. By textural classes, 85% of the fine textured samples were estimated within .05 of the oven dry volume weight as compared with 69% for the medium textured soils containing less than 40% silt. Collaborators estimated volume weights as accurately as the author.

Table 7: Field method for estimating volume weights, by texture and % of readily available moisture, using snow tube balance readings for three Uhland core samples in a pail:

Texture 1

Volume Wt.	% readily available moisture 0	1/4	1/2	3/4	F
1.10	51.1	53.0	54.5	56.0	57.6
1.15	53.0	54.0	56.4	57.9	59.4
1.20	54.8	56.7	58.2	59.7	61.3
1.25	56.7	58.5	60.0	61.6	63.1
1.30	58.5	60.3	61.8	63.4	65.0
1.35	60.2	62.2	63.7	65.2	66.8
1.40	62.2	64.0	65.6	67.1	68.6
1.45	64.0	65.9	67.4	68.9	70.5
1.50	65.9	67.8	69.3	70.8	72.4
1.55	67.8	69.6	71.1	72.6	74.2
1.60	69.6	71.4	73.0	74.5	76.1
1.65	71.4	73.3	74.8	76.3	77.9

Texture 2

Volume Wt.	% readily available moisture 0	1/4	1/2	3/4	F
1.10	48.0	49.9	51.4	53.0	54.5
1.15	49.9	51.7	53.3	54.8	56.4
1.20	51.7	53.6	55.1	56.7	58.2
1.25	53.6	55.4	57.0	58.5	60.0
1.30	55.4	57.2	58.8	60.3	61.8
1.35	57.3	59.1	60.6	62.2	63.7
1.40	59.1	61.0	62.5	64.0	65.6
1.45	61.0	62.8	64.3	65.9	67.4
1.50	62.8	64.7	66.2	67.8	69.3
1.55	64.7	66.5	68.0	69.6	71.1
1.60	66.5	69.4	69.9	71.5	73.0
1.65	68.4	70.2	71.7	73.3	74.8

Texture 3

Volume Wt.	% readily available moisture 0	1/4	1/2	3/4	F
1.10	47.1	49.0	50.5	52.0	53.6
1.15	49.0	50.8	52.3	53.9	56.4
1.20	50.7	52.6	54.2	55.7	57.2
1.25	52.7	54.5	56.0	57.6	59.1
1.30	54.5	56.4	57.9	59.4	61.0
1.35	56.4	58.2	59.7	61.3	62.8
1.40	58.2	60.0	61.6	63.1	64.6
1.45	60.0	61.9	63.4	65.0	66.5
1.50	61.9	63.8	65.3	66.8	68.4
1.55	63.8	65.6	67.1	68.7	70.2
1.60	65.6	67.4	69.0	70.5	73.1
1.65	67.4	69.3	70.8	72.4	73.9

Texture 3

Volume Wt.	% readily available moisture 0	1/4	1/2	3/4	F
1.10	45.6	47.4	49.0	50.5	52.1
1.15	47.4	49.3	50.8	52.3	53.9
1.20	49.2	51.1	52.6	54.2	55.7
1.25	51.1	53.0	54.5	56.0	57.6
1.30	52.9	54.8	56.4	57.9	59.4
1.35	54.8	56.6	58.2	59.7	61.3
1.40	56.6	58.5	60.0	61.6	63.1
1.45	58.5	60.3	61.9	63.4	65.0
1.50	60.4	61.2	63.8	65.3	67.0
1.55	62.2	64.1	65.6	67.1	68.7
1.60	64.2	65.9	67.4	69.0	70.5
1.65	65.9	67.8	69.3	70.8	72.4

<u>Texture</u>: Texture alone is not a satisfactory indication of average irrigation intake rates. Figures 8 and 9 show that some fine and moderately fine textured soils have average irrigation intake rates similar to moderately coarse textured soils. There are wide variations in irrigation intake rates within all textural separations. The widest spread in values occurs in medium textured soils containing less than 40% silt and the narrowest spread occurs in the medium textured soils containing more than 40% silt. It is important therefore to make this separation in the medium textured soils.

A 20X pencil type hand lens and a one inch square Ronchi ruling[3] with 175 lines per inch are very useful in estimating the percentage of silt in medium textured soils. Powder a pinch of dry soil and drop the soil on the Ronchi ruling; examine with the 20 power pencil type hand lens. (Errors have been made in estimating the percentage of silt through the use of a 7X lens.) Silt particles fall entirely between the lines of the Ronchi ruling since the spacing between the thick lines is .07 mm. The upper diameter limit of silt is .05 mm.

Preliminary data indicate that we may need to recognize those medium textured soils in which the silt fraction consists mostly of coarse silt .02 - .05 mm. In a few of these soils, the core rates were similar to medium textured soils containing less than 40% silt. Additional studies are needed.

<u>Effective pores</u>: Effective pores are determined from the following formula which was derived from core permeability data (11):

$$\text{Effective pores per square foot} = \frac{\text{No. of pores } 1/40 - 1/20'' \text{ dia.}}{5} + \text{No. of pores larger than } 1/20'' \text{ dia.}$$

The number of pores can be determined either from clods or from cores broken in half. Probes which are 1/40 and 1/20 inch in diameter respectively are used to determine size classes. To avoid counting pits, the probes are inserted at least 1/8 inch into the pore before including it in the count. Suitable probes can be made by straightening out paper clips.

3. Suggested by Milo S. James, Survey Supervisor.

Compact, medium textured soils had average irrigation intake rates in excess of one inch per hour when the limiting layer in the surface foot contained 21 or more effective pores per square foot. Medium textured silty soils containing more than 3% organic matter and more than 21 effective pores per square foot also had average irrigation intake rates in excess of one inch per hour. Core data from moderately fine textured soils indicate that these soils also would have intake rates in excess of one inch per hour if 21 or more effective pores are present. In contrast, medium textured soils containing more than 40% silt but less than 3% organic matter appear to be too unstable for the "effective pores" to change appreciably the irrigation intake rate.

Stability: If we include stability along with compaction, texture and effective pores, the irrigation intake rates of many soils can be predicted. The best field method of estimating stability is the drop test (11.) Select a lump of soil 1/8 to 1/4 inch in diameter and record number of drops of water to slake it. Use ordinary dropper bottle and water, holding the tip of the dropper about one inch above the lump.

Unstable	- lumps melting with 10 drops or less.
Moderately stable	- lumps melting with 11 to 25 drops.
Stable	- lumps remaining intact after receiving 25 drops.

This test should be used when less than half of the readily available moisture is present, since some silty soils remain intact when the moisture content is higher. Within the same class of texture and degree of compaction, unstable soils have lower intake rates than stable soils.

Medium textured soils containing more than 40% silt which are unstable usually have average irrigation intake rates of less than .5 in/hr, whereas moderately stable soils of similar texture have average irrigation intake rates approaching one inch per hour. Limited data indicate that unstable silty clay loam soils containing more than 25% two micron clay tend to have higher intake rates than unstable medium textured silty soils.

Why should silty clay loams tend to have higher intake rates than silt loams and loams having more than 40% silt? The reason seems to be that silt is clogging material (9.) In the medium

textures containing more than 40% silt, there appears to be insufficient clay to form stable aggregates. Although legumes and grasses give temporary improvement, the aggregates are mostly unstable and the pores soon clog with silt. In contrast, the pores do not clog as readily in the finer textures since the higher clay content can aggregate more of the silt particles (10.)

Is the percentage of organic matter in the surface soil related to intake rates? Nearly all of the soils we have studied have less than 3% organic matter. In this range, it appears that organic matter is a minor influence and other factors mask any effect it may have. Limited data from high mountain valleys in Colorado indicate that intake rates are higher when the percentage of organic matter exceeds 3%. Since these soils also contain numerous effective pores, it is difficult to evaluate the effect of organic matter.

J. A. Williams has found that the percentage of <u>dispersion of silt plus clay</u> indicates some unstable soils which ordinarily would be expected to be stable, based on the percentage of .005mm. clay. Medium textured soils containing more than 40% silt and less than 3% organic matter usually contain more than 80% dispersed silt plus clay. The saturated permeability rates of these soils is usually less than .5 in/hr. Such soils are unstable and occur widely in southern Arizona, southern New Mexico and alluvial soils throughout Region 6. The dispersion of silt plus clay often substantiates the drop test in showing that many silty soils are unstable. Limited infiltration data from both the high plains and southeastern Utah, however, indicate that the drop test may be more reliable than dispersion of silt plus clay in indicating soils with slow intake rates. Additional studies are needed.

Low dispersion percentages of .005 mm. clay do not correlate consistently with satisfactory intake rates since the clogging effect of the silt is not fully evaluated, but high dispersion values of .005 mm. clay are usually associated with alkali-affected soils, which usually have low intake rates.

<u>Alkali</u>: To learn more about the factors affecting intake rates on alkali affected land and the influence of amendments, tenth acre plots, in triplicate, were established in November 1945 at the Albuquerque Nursery on soil unit 32P2 A_3. Three treatments were applied: 9 tons of gypsum per acre, 2 tons of sulfur per acre and one ton of sulfur per acre. During a period of two

years, irrigation intake rates were determined from five inch irrigations. Gypsum gave the highest and most uniform intake rate, approaching one inch per hour. The sulfur plots were extremely variable and gave rates intermediate between the check and gypsum. During a two year period, the intake rates on the check plots slowly decreased to nearly .0.

You often need to know how fast unstable alkali-affected soils take water. Are 1:5 pH values and percent of dispersion of five micron clay helpful? Such data are shown in Figure 13. Irrigation intake rates were less than .1 inch per hour on soil unit $\overline{3}$2P2 A_3 when 1:5 pH exceeded 9.1. For pH values varying from 8.4 to 9.1 and when the dispersion percentage of five micron clay exceeded 30%, irrigation intake rates were between .1 and .2 in/hr. Intake rates approached or exceeded one inch per hour when the percentage of dispersion was less than 16 and pH values ranged from 8.1 to 8.7. The use of both gypsum and sulfur on alkali soils, followed by leaching irrigations, increased irrigation intake rates and reduced both the percentage of dispersion and pH.

Fireman and Wadleigh (7) have pointed out the lack of correlation between pH and exchangeable sodium in degraded alkali soils. However, such soils are usually dispersed. H. J. Maker reports that some marly material (L) from southeastern New Mexico has 1:5 pH values in excess of 9.0 but both exchangeable sodium and dispersion are low. The combination, however, of 1:5 pH values above 9.0 and high percentage of dispersion usually indicates both low intake rates and alkali soils.

Exchangeable sodium through its influence on both stability and swelling does influence intake rates. In general, medium to heavy textured soils having exchangeable sodium in excess of 15% will have average irrigation intake rates of less than .5 in/hr. On a regional basis, however, exchangeable sodium is not directly related to intake rates. Other factors, such as volume weight, % silt, swelling due to different types of clays and quality of water, appreciably modify such rates.

Depth of water: According to Darcy's law, permeability is proportional to the hydraulic gradient. The average irrigation intake rate should increase if the average depth of water is increased. Typically, the average depth of water in most border irrigations is 3 inches when the water is shut off at the ditch. However, depths of 4 inches often occur on pasture, alfalfa and heavy mulch when the grade is less than .2%. In contrast, the

INTAKE RATES INCREASE WHEN DISPERSION AND pH ARE REDUCED BY EITHER GYPSUM OR SULFUR

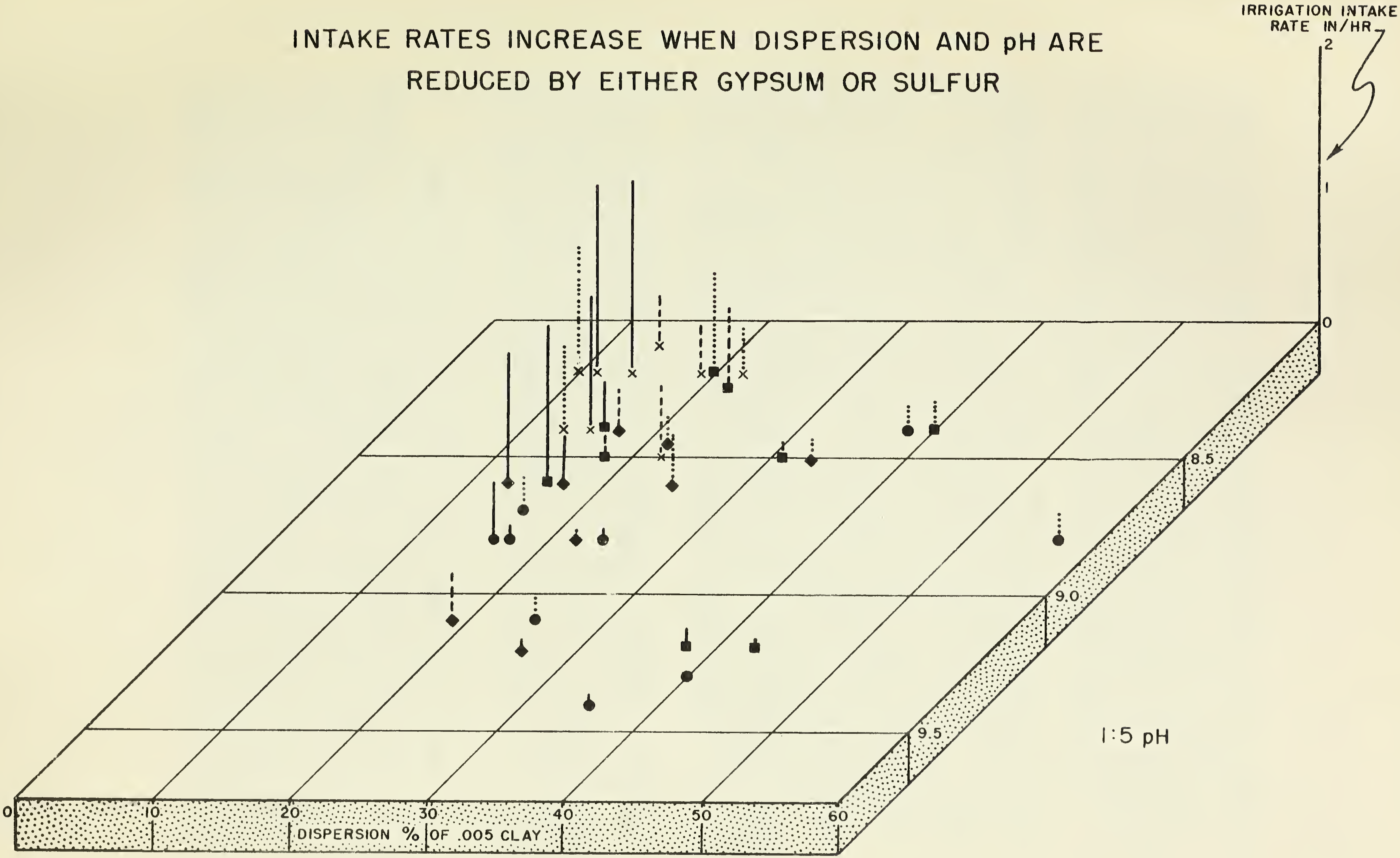

Figure 13. Percentage of .005 clay dispersed and 1:5 pH for the 0–6 inch layer and irrigation intake rates from five inch irrigations (·····) July 1946, (– –) July 1947, (—) March 1948; by treatments (●) check, (×) 9 tons of gypsum per acre, (◆) 1 ton of sulfur per acre, (■) 2 tons of sulfur per acre on soil unit $\bar{3}2P2A_3$, Albuquerque Soil Conservation Nursery.

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depth of water in most furrow irrigations is one inch or less on grades as low as .2%. The depth of water in furrow irrigations approaches that of border irrigations in flat, level areas. Thus, on the same soil, on sloping land, you would expect higher intake rates from border irrigations than from furrow irrigations, but factors such as furrow spacing and the presence of effective pores, preclude the direct application of Darcy's law. Rowhrer also found that ditch losses did not fit Darcy's law (16.)

Furrow spacing: Criddle (3) has indicated in a table for furrow spacing that a flow of one gallon per minute per 100 feet of row would have an intake rate of .65 in/hr for 18-inch furrow spacinc and .32 inch per hour for a 36-inch furrow spacing. It does not follow, however, that doubling the number of furrows doubles the intake rate for all soils. In some highly permeable soils which sub slowly to the row, you could double the average intake rate for the area by doubling the number of furrows. On the other hand, in medium textured soils underlain by a tillage pan, lateral movement of moisture soon meets the moisture from the next furrow. Under these conditions, doubling the number of furrows, say from a 36-inch spacing to an 18-inch spacing, would affect intake rates relatively little after the first hour. Both speed of subbing and length of irrigation as well as furrow spacing affect average furrow irrigation intake rates.

The maximum allowable stream per furrow or corrugation is an additional factor influencing intake rates. At Eagle, Colorado, intake rates from erosive flows were nearly double those of allowable flows on slopes varying from 5 to19%. On these slopes, maximum allowable flows are so small that relatively little of the soil surface is covered by water. Hence, furrow intake rates are much below the capacity of the soil to take water.

Predicting Irrigation Intake Rates from Uhland Cores

Method: In our first determinations of permeability rates using saturated Uhland cores, we found that these rates were much below average irrigation intake rates for the same area. Therefore, we determined the median intake rate from a minimum of 6 cores per layer (17) for both the first and second hour for samples taken at field moisture. Usually, these samples were taken just before our irrigation trial. Now, how do you integrate the core intake values for the different depths? We found on dry farm lands that we improved our estimates of intake rates by consider-

ing both the volume of readily available moisture that had been used by plants and the volume of temporary storage that could be filled (5.)

Predicted average irrigation intake rates were calculated as follows:

A. The median core rate of the surface soil (1/2 - 3-1/2" depth) during the first hour at field moisture was used:

   1. Until the surface soil above the tillage pan or subsoil was filled, if one hour or less was required.

   2. If the surface soil was not filled at the end of one hour, then the second hour median core rate for the surface soil was used until the surface soil was filled.

B. The core rates from underlying layers were used in a similar manner to that of the surface soil until the total depth applied during the irrigation was accounted for.

Results: In Figure 14, a perfect correlation between actual and predicted average irrigation intake rates would be a line making a 45 degree angle with the base of the graph, with zero as the starting point. There is a reasonable correlation between predicted irrigation intake rates and average irrigation intake rates derived from field trials for both border irrigation and furrow irrigation. Considering the small area represented by a minimum of six cores, three inches in diameter, as compared with the area studied in the field trials, it is surprising that there is not more variation. Although irrigation intake rates can be predicted roughly from core intake rates and storage values, the direct determination of irrigation intake rates yields more information per man hour spent.

Core intake rates have been very helpful in locating layers which limit irrigation intake rates. Clues developed from these core studies (11) have been very helpful in grouping soils which possess similar intake rates. Such clues are compaction, 40% silt, drop test and the number of effective pores. Further discussion will be presented in a separate paper.

USABLE CORRELATION BETWEEN AVERAGE IRRIGATION INTAKE RATES AND 0-2 HOUR CORE INTAKE RATES

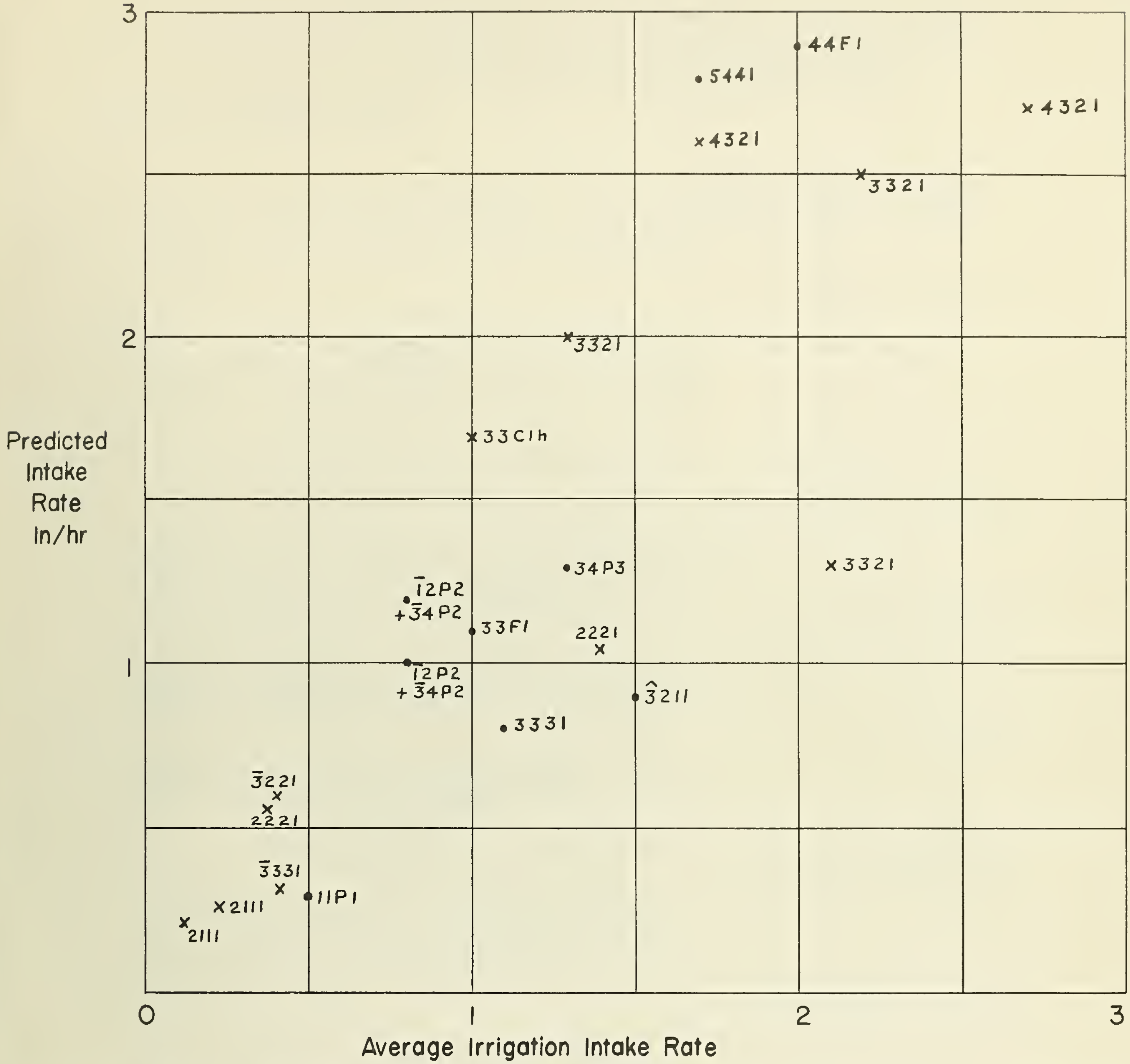

Figure 14. Relation between predicted intake rates from Uhland core data 0-2 hours and average irrigation intake rates for border irrigation (•), furrow irrigation (×) by soil units in Arizona, Colorado and New Mexico.

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Grouping Soils by Intake Rates

The following clues for grouping soils by intake rates are based on the texture of the surface soil, the compaction and number of effective pores in the limiting layer in the surface foot:

Clues to Grouping Soils:

	Border in/hr	Furrow in/hr
Slow Irrigation Intake Rates - 0.0 - 1.0 in/hr		
Medium to fine textured soils affected by alkali	.0- .5	.0- .5
Medium textured soils containing more than 40% silt, not alkali but usually unstable, 0 to 3% organic matter:		
Slake with less than 10 drops of water	.0- 1.0	.0- .5
Require more than 10 drops of water to slake	.5- 1.0	.5- 1.0
Compact 1, 2, 3 textures containing less than 21 effective pores per square foot in the limiting layer in the surface foot	.0- 1.0	.0- 1.0
Compact 4 and 03 textures containing less than 21 effective pores per square foot in the limiting layer in the surface foot	- - -	.0- 1.0
Moderate Irrigation Intake Rates - 1.0 - 2.5 in/hr may be Expected		
Firm 1, 2, 3 textures	1.0- 2.5	1.0- 2.5
Moderately compact 4, 5 and 03 textures containing less than 21 effective pores per square foot in the limiting layer in the surface foot	1.0- 2.5	- - -
Medium textured silty soils containing more than 3% organic matter and more than 21 effective pores per square foot in the limiting layer in the surface foot	1.0- 2.5	1.0- 2.5

	Border in/hr	Furrow in/hr
Moderately compact and compact 2 and 3 textures containing more than 21 effective pores per square foot in the limiting layer in the surface soil	1.0- 2.5	- - -
<u>Excessive Irrigation Intake Rates 2.5 + in/hr (clean irrigation water) may be expected</u>:		
Firm 4, 5, 03, $\overline{0}3$ textures	2.5 +	2.5 +
Firm to loose 2 and 3 textures first irrigation following seedbed preparation (not to be used in grouping soils)	2.5 +	2.5 +

Are all irrigation trials satisfactory for determining the intake rate class for a soil? No, the first irrigation of the season and the first irrigation following a major tillage operation such as plowing or disking should be excluded. Irrigation intake rates determined from these conditions are often two or more times as high as succeeding irrigations. Irrigation intake rates following tillage in our studies were higher than succeeding irrigations without tillage. If no cultivation occurs between irrigations, intake rates have been very comparable on the same field for succeeding irrigations.

<u>Efficiency of Irrigation</u>

Efficiency of irrigation is the percentage of the water applied to the field which is retained in the root zone. Efficiency of irrigation is reduced by both surface waste water off the field and by deep percolation beyond the root zone.

<u>Surface waste water</u>: You can eliminate surface waste water if you hold all of the water applied on the area irrigated. At the Albuquerque Nursery, the average irrigation efficiency was 81% for 21 border irrigation trials without surface waste water. The grade varied from .0 to .3%. The surface soils were medium to fine textured and were underlain by sand at depths of from 20 to 36 inches. The borders were planted with grass in rows three feet apart. By choosing the proper length of run, by applying the minimum depth of water required to cover a border and by

ponding the water on the lower end of the border, surface waste water can be eliminated on grades of .0 to .3%.

On slopes steeper than .3%, it is usually necessary to waste water in both border and furrow irrigations in order to obtain adequate penetration. In furrow irrigation, the amount of surface waste water usually decreases as the intake rate increases, as shown in Table 8.

Table 8: Influence of slope and intake rate on surface waste water, 21 furrow irrigation trials in Arizona, New Mexico, Colorado and Utah:

Slope %	Percent of Water Wasted by Intake Rate Classes Slow .0 - 1.0 in/hr	Moderate 1.1 - 2.5 in/hr	Excessive 2.5 + in/hr
.0 - .3	-	1	1
.4 - 1.0	22	4	-
1.1 - 3.0	24	-	9

Deep percolation losses are usually serious in both border and furrow irrigation for soils which have moisture use values (MUD) of less than 4 inches, Table 9. You would expect deep percolation losses to decrease as the moisture use capacity increases. Table 9, however, shows that serious deep percolation losses are not confined to soils having MUD values of less than 4 inches.

Even with a good border irrigation layout, you may have serious deep percolation losses, if you irrigate when the soil approaches field capacity. Under these conditions we measured a 22% deep percolation loss on deep soils with MUD values of 5.1 to 6.0 inches. For these soils, the intake rates were less than one inch per hour. To avoid these losses, you need to know how to apply the depth of water required to fill the root zone and when to apply it.

Even with a good furrow irrigation layout, you may have serious deep percolation losses on soils with intake rates in excess of 2.5 in/hr, if the flow of water is slightly less than or just equal to the intake rate for the entire set. On soil unit

O3HJ2 near Provo, Utah, deep percolation losses were reduced from 5.2 inches to 0.0 by increasing the flow per furrow from 22 g.p.m. to 35 g.p.m. The slope was 1.4% and the furrows were 360 feet long. The lower rate of flow was approximately equal to the intake rate of the set, hence excessive time was required to cover the furrows.

Table 9: Relation between intake rates and deep percolation losses by MUD classes from 31 border irrigations and 21 furrow irrigations in Arizona, Colorado, New Mexico and Utah:

Moisture Use by Alfalfa (MUD) Inches 0 - 5'	Average Percentage of Water Lost by Deep Percolation					
	Border Irrigation Intake Rates			Furrow Irrigation Intake Rates		
	.0 - 1.0 in/hr	1.1 - 2.5 in/hr	2.6 + in/hr	.0 - 1.0 in/hr	1.1 - 2.5 in/hr	2.6 + in/hr
3.0 -3.9	12	21	34	35	0	34
4.0 -4.9	6	11	-	29	12	0
5.0 -6.0	22	10	4	3	0	38

Heavy grass mulches increased deep percolation losses on moderately deep soils at the Albuquerque Nursery, which were border irrigated. With a mulch present, the average deep percolation loss was 35%, based on 17 trials from 4 fields. After removing the mulch from these fields, the deep percolation loss dropped to 15%, based on 21 trials.

<u>The minimum depth of water that will adequately cover an area is</u> primarily determined by the intake rate. Figure 15 shows that intake rates in excess of 2.5 in/hr often require a depth of 4 or 5 inches to cover borders from 400 to 600 feet in length even when large flows of water are used. Such depths of water result in serious deep percolation losses on soils with MUD values of less than 4.0 inches. Recognition of the correct intake rate class in designing the irrigation layout is essential in reducing deep percolation losses.

Minor factors determining the minimum depth of water applied in border irrigations were: Slope varying from .0 - .7%, lengths

INTAKE RATE DETERMINES MINIMUM DEPTH OF WATER APPLIED MORE THAN % GRADE AND LENGTH OF BORDER

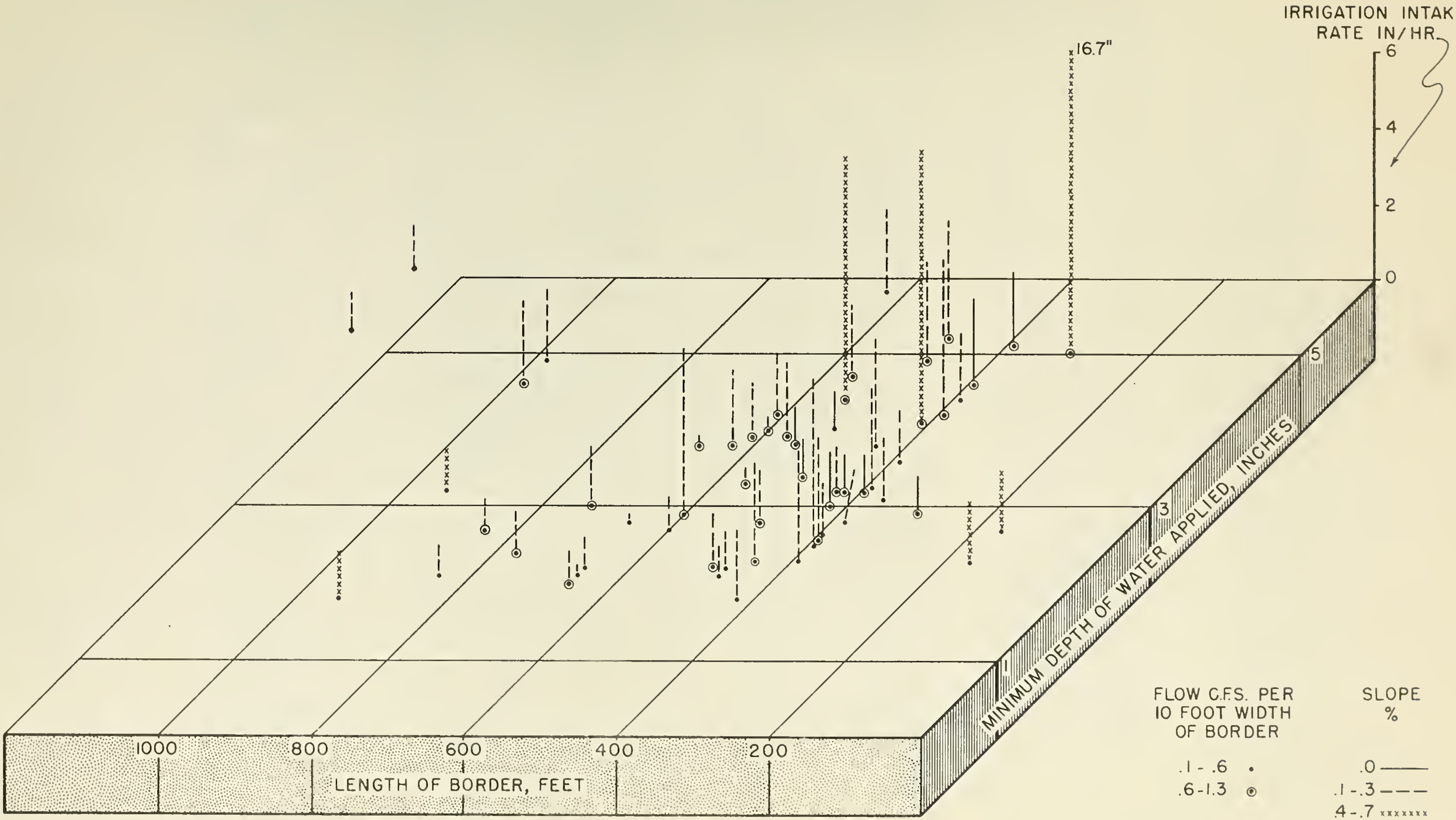

Figure 15. Relation between minimum depth of water applied in border irrigation and length of border, irrigation intake rate, flow c.f.s. per 10 foot width of border and % slope for row crops, pasture and alfalfa.

of border varying from 160 to 1260 feet, flows varying from .1 to 1.3 c.f.s. per 10 foot width of border, row crops versus pasture and alfalfa. Although these factors do influence the minimum depth of water applied, they all appear to be secondary to intake rate for the areas studied, Figure 15.

Adequacy of penetration: Unfortunately, the term irrigation efficiency does not evaluate the amount of unfilled storage following an irrigation. For example, we made an irrigation trial at Roswell which had nearly 100% irrigation efficiency but there was dry soil at a depth of two feet. Thus, irrigation efficiency is a measure of the water held in the root zone but does not necessarily show how much of the root zone is brought to field capacity.

Good crop production is dependent in many areas upon filling the root zone to field capacity to a depth of five feet during the preplanting irrigation and to three feet in succeeding irrigations. Unless you can afford to waste surface water, it is difficult to obtain uniform penetration in soils with intake rates of .0 to 1.0 in/hr without leveling to grades of .00 to .05. On some of the more slowly permeable soils, sufficient grade and leveling to prevent prolonged ponding may be required to prevent scalding damage to crops such as alfalfa.

Uniform cross grades and elimination of high spots are especially important on soils that have intake rates of less than 1.0 in/hr. Flat leveled borders with high spots of .1 and .2 feet at the Albuquerque Nursery have required from .5 to 1.0 inch more water per irrigation than similar borders without high spots. Even with this additional volume of wat crops showed stress earlier in the high spots. Yields were reduc d, owing not only to inadequate penetration in the subsoil but also to more severe red spider infestations. The highest degree of leveling is required on soils with intake rates of .0 - 1.0 in/hr in order to obtain uniform penetration of moisture and efficient use of water.

Efficient use of water and satisfactory penetration have been obtained on soils with intake rates of 1.1 to 2.5 in/hr by leveling to grades varying from .1 to .3%. Although the data are preliminary, uniform cross slopes and the elimination of high spots appear to be more important than whether the grade is .1 or .2%. On moderately deep soils, as much as half of the commercial nitrogen applied was leached out of the root zone in an

area where water was ponded by a high spot in border irrigation. In general, satisfactory penetration can be obtained on soils with intake rates of 1.1 to 2.5 in/hr, using less refined methods of leveling than you would use on soils with slow intake rates.

Grades in excess of .3% may cause inadequate penetration if the borders are short and if no surface water is wasted. Inadequate penetration occurred in a .6% grade in the upper part of a border 36' x 167' in spite of a flow of only .7 c.f.s., when muddy water was used on soil unit 5441. The intake rate in this border of alfalfa was 1.7 in/hr. The border length should be increased on this coarse textured surface soil owing to the use of muddy water.

Soils with intake rates in excess of 2.5 in/hr do not need to be leveled to grade as carefully as soils with lower intake rates <u>if high spots are eliminated</u>. Since you can usually irrigate these soils in less than an hour, you must cover the entire area quickly if you are to obtain uniform penetration. The elimination of high spots is more important than obtaining a uniform grade.

<u>Irrigation Layout</u>

<u>Length of border</u>: Suggested lengths of borders are presented in Table 10 by intake rate classes and the moisture use by alfalfa (MUD.) This tentative table has been developed from irrigation trials (which have included soil moisture samples) to determine uniformity of penetration as well as deep percolation losses. Using the lengths of border suggested for specific flows of water, you should obtain irrigation efficiencies of 80% and uniform penetration for grades of .0 - .3%.

Table 10: Tentative lengths of borders for high irrigation efficiencies and uniformity of penetration by intake rate classes and moisture use by alfalfa (MUD):

Moisture use by Alfalfa (MUD) Inches for 5' Section	Flow per 10' width c.f.s.	Length of Border, Feet — Average Irrigation Intake Rate: .0-1.0 in/hr .0	- .1%	1.1-2.5 in/hr .1 - .3%	2.6+ in/hr 1. - .3%
3.0 - 3.9	.3 - .6	400	---	400	300
3.0 - 3.9	.9 - 1.2	500	---	500	400
4.1 - 4.9	.3 - .6	500	1000	600	350
4.1 - 4.9	.9 - 1.2	550	---	800	450
5.0 - 6.0	.3 - .6	600	1320	660	400
5.0 - 6.0	.9 - 1.2	660	---	880	500

The following conditions should be considered in using Table 10:

1. Selection of correct irrigation intake rate class:

   a. Determine the minimum intake rate when a mature or nearly mature crop is present. Avoid both the first irrigation of the season and the first two irrigations following seedbed preparation, since these conditions often give intake rates several times higher than later irrigations. Avoid irrigations when the readily available moisture in the surface foot exceeds 3/4 readily available moisture.

2. Selection of moisture use class for rapid growth of alfalfa (MUD):

   a. Determine the correct MUD value for the soil unit you wish to evaluate (Table 3.)

      3.0 - 3.9 inches - Three inch irrigations are adequate to maintain rapid growth of alfalfa. Except on soils with intake rates of less than 1.0 in/hr, it is difficult to avoid leaching irrigations of row crops.

      4.0 - 4.9 inches - Plan to use from 4 to 5 inches of water per irrigation for alfalfa and from 2-1/2 to 3 inches for row crops.

      5.0 - 6.0 inches - Plan to use 5 to 6 inches of water per irrigation for alfalfa and 3 inches for row crops.

   b. Note that in areas of water shortage and also in areas where cotton is allowed to exhaust the available soil moisture, you may need to plan to apply as much as 10 inches of water to fill the 0 - 5 foot depth of the soils during the preplanting irrigation. In such areas, consider CAM values Page 11 in designing irrigation layouts.

Speed of irrigation: Under field conditions, how much faster can you irrigate by using a large stream? In Figure 16, the time required to apply 4 inches of water to one acre, using borders 40 feet wide, is shown in hours for different flows of water. By doubling the size of stream applied, from .4 c.f.s. per 10 foot width to .8 c.f.s., you may reduce the time required to irrigate one acre from 2.6 hours to 1.3 hours. The curve shown in Figure 16 is almost identical with one constructed for 80 border irrigations which averaged 40 feet in width. If you can secure high irrigation efficiency and uniform penetration with larger flows, you can sharply reduce the cost of irrigating.

Can you reduce the minimum volume of water applied per border by increasing the size of stream? Our studies show that by using borders 50 feet wide, which were flat leveled, we could reduce the amount of water applied until flows exceeded 5.0 c.f.s. (1.0 c.f.s. per 10 foot width of border.) Above this point, the average irrigator does not think fast enough to save water, although irrigation time per acre can be reduced with skilled help.

Maximum allowable stream furrow irrigation: The maximum allowable stream per furrow which can be used without causing serious losses of topsoil is influenced by both the stability of the surface soil and by the texture. For example, the maximum allowable flow is 12 gallons per minute per furrow for one percent slopes,.on heavy, moderately heavy and unstable medium textured surface soils (Figure 17.) In contrast, you could safely apply 40 g.p.m. per furrow on one percent slopes, on stable, medium textured soils containing less than 40% silt, gravelly, medium textured soils and moderately light textured surface soils. However, where these soils are compact, maximum allowable streams cannot be used owing to inadequate penetration. In conclusion, our preliminary data show that at least two groups of soils should be recognized in setting up the maximum allowable stream, by percent of slope.

LARGER FLOWS SPEED UP IRRIGATION

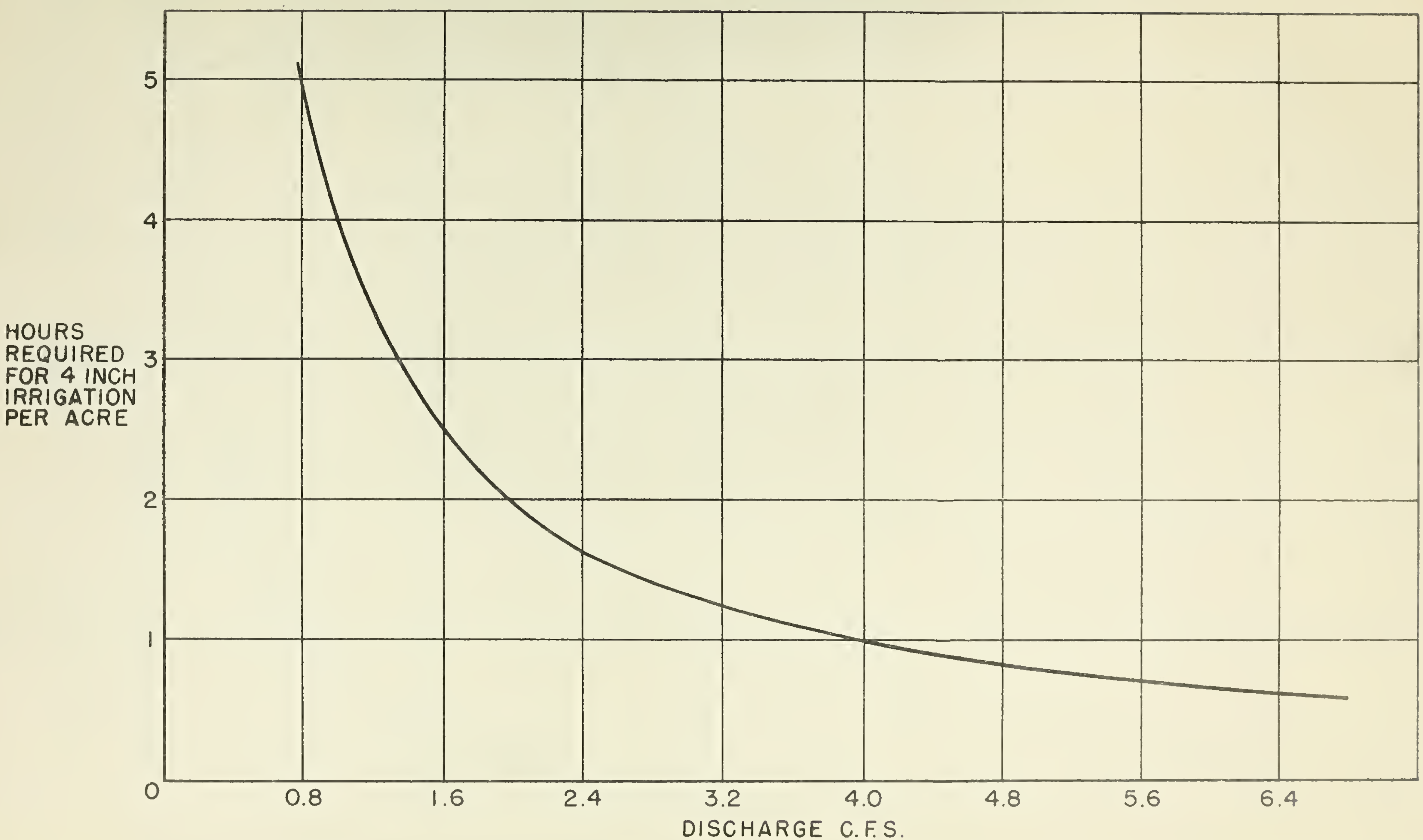

Figure 16. Relation between discharge and time reguired to apply 4 inch border irrigation on borders 40 ft. wide

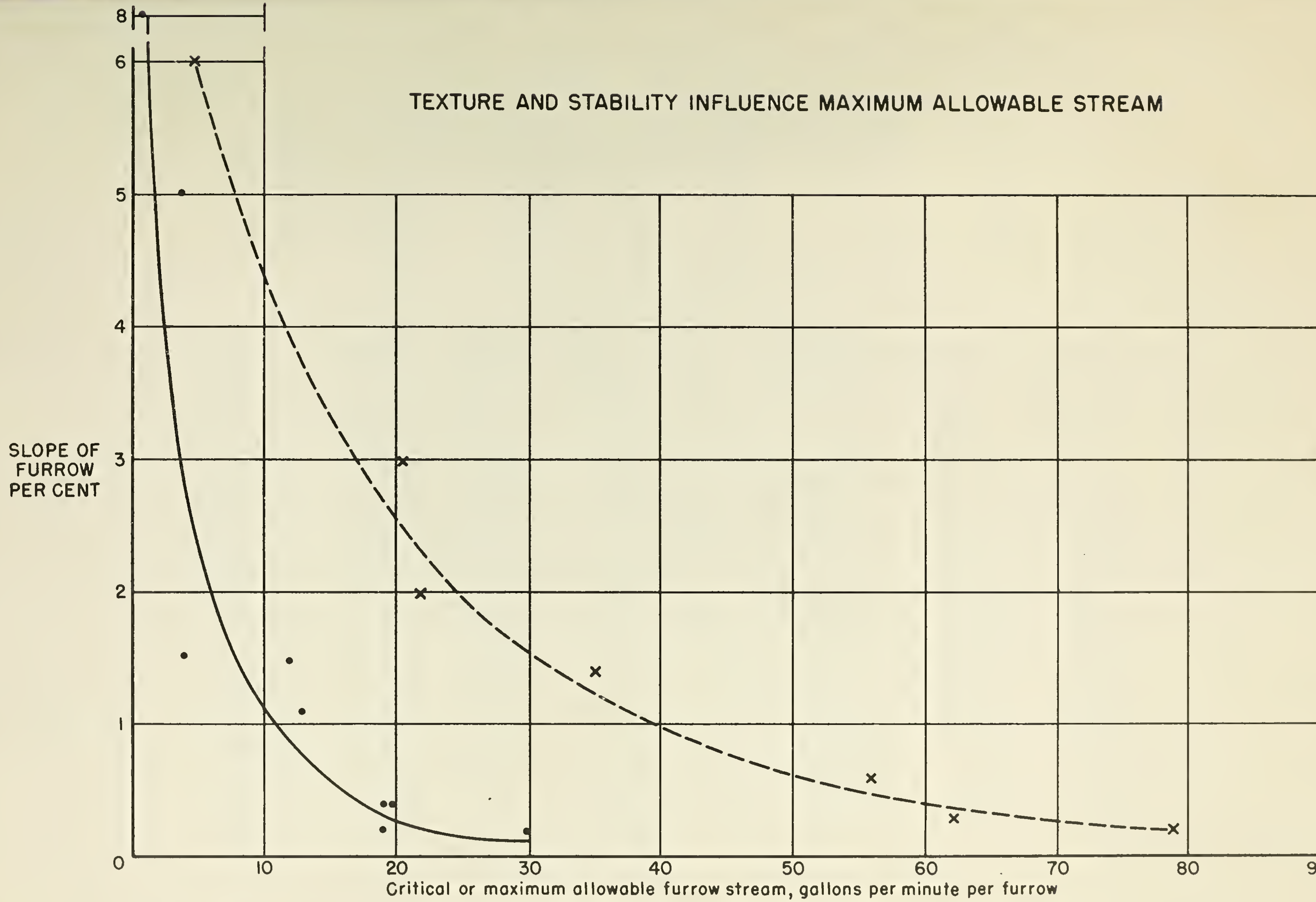

Figure 17. Relation between maximum allowable stream per furrow, slope and surface texture: 1, 2, $\bar{3}$ (—); 3, 03, 4 (— —) from furrow irrigation trials in Arizona, Colorado, New Mexico, and Utah (tentative).

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